TRANSACTIONS

AND

PROCEEDINGS

OF THE

ROYAL SOCIETY OF NEW ZEALAND

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(QUARTERLY ISSUE)

PART 1, JUNE, 1942

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OF

THE ROYAL SOCIETY OF NEW ZEALAND

MINUTES OF THE ANNUAL MEETING OF THE COUNCIL, 20th MAY, 1942.

THE ANNUAL MEETING of the Council of the Royal Society of New Zealand was held in the Council Room, Victoria University College, Wellington, on Wednesday, 20th May, 1942, commencing at 10 a.m.

Roll Call: The following were present:—

President: Lieutenant-Colonel G. Archey.
Vice-President: Dr. H. H. Allan.
Government Representatives: Mr. B. C. Aston, Dr. W. R. B. Oliver.
Auckland Institute Representatives: Professor H. W. Segar, Mr. A. T. Pycroft.
Wellington Branch Representatives: Dr. H. H. Allan, Dr. L. I. Grange.
Canterbury Branch Representatives: Dr. F. W. Hilgendorf, Dr. R. A. Falla.
Otago Branch Representative: Dr. F. J. Turner.
Hawke's Bay Branch Representative: Mr. G. V. Hudson.
Manawatu Branch Representative: Mr. M. A. Eliott.
Nelson Institute Representative: Dr. D. Miller.
Southland Branch Representative: Professor W. P. Evans.
Co-opted Member: Dr. P. Marshall.

Apologies for Absence were received from His Excellency the Governor-General, the Hon. the Minister of Scientific and Industrial Research, Professor E. R. Hudson, and Dr. C. M. Focken.

Council: The President welcomed back to the Council Professor W. P. Evans, who had been asked to represent the Southland Branch on the Council, and Mr. A. T. Pycroft, representative of the Auckland Institute; he also welcomed a new member, Dr. Grange, one of the representatives of the Wellington Branch.

Presidential Address: Before commencing his Presidential Address, Lieutenant-Colonel Archey referred to the loss the Society had sustained by the death of two distinguished scientists whose names the Society was honoured to have on its roll of Honorary Members—Sir Arthur W. Hill, Director of the Royal Botanic Gardens, Kew, and Sir William Bragg, Director of the Royal Institution of Great Britain and the Davy Faraday Research Laboratory.

Lieutenant-Colonel Archey then delivered his address, at the conclusion of which Dr. Allan moved that the President be cordially thanked for his inspiring address and that he be asked to allow it to be printed in the *Transactions*. This motion was carried by acclamation.

Notices of Motion were called for, to be considered later in the meeting.

Hector Award: The following report of the Hector Award Committee was read:—

The Committee appointed to consider the award of the Hector Medal and Prize for 1942, consisting of the following members: Professor H. B. Kirk, Dr. W. R. B. Oliver, and the Rev. Dr. J. E. Holloway, has unanimously decided to recommend that the award be made to Dr. H. H. Allan for his work in New Zealand Botany.

(Signed) JOHN E. HOLLOWAY,

May 3, 1942. Convener of Committee.

The recommendation of the Hector Award Committee was unanimously adopted.

Amount of Hector Prize: On the motion of the Hon. Treasurer (Mr. M. A. Eliott), it was resolved that the amount of the prize be £50.

Election of Fellows: The President read the report of the Fellowship Selection Committee as follows:—

The Fellowship Selection Committee elected at the Annual Meeting held in May, 1941, after duly considering the votes recorded by existing Fellows, the scientific work of those nominated, and the distribution of Fellows between the various sciences, unanimously recommend the Council to elect Dr. L. H. Briggs and Dr. L. I. Grange, Fellows of the Society.

(Signed) W. P. EVANS,

April 20th, 1942. Convener Fellowship Selection Committee.

On the motion of Professor Evans, seconded by Dr. Marshall, the recommendation of the Fellowship Selection Committee was adopted.

Method of Selection of Fellows: The President read a letter from the Convener of the Fellowship Selection Committee regarding the voting by Fellows. The letter pointed out that some Fellows continue to ignore the instructions given to indicate the full number of preferences, and this growing tendency to plumping or partial plumping could lead to an entirely unfair result in the voting. The wisdom of asking Fellows to indicate a greater number of preferences than the number of Fellows to be elected was also questioned.

After some discussion on these points, Professor Evans moved, Dr. Marshall seconded, and it was carried: "That in future Fellows be instructed to vote for the number of Fellows to be elected, and that in the instructions issued to Fellows it be indicated that failure to adhere to this instruction will render the vote informal."

The President thanked Professor Evans for bringing the matter before the Council.

Honorary Membership: The question of allowing a late nomination from a Member Body came before the Council and on the explanation of the representative of the Branch as to the reason of the delay in forwarding the nomination it was resolved on the motion of Mr. Pycroft to allow the nomination to be considered. The President read the qualifications accompanying the nomination,

and after a short discussion regarding the nominees the election proceeded and resulted in Field-Marshal J. C. Smuts being elected.

Member Bodies' Reports and Balance Sheets: The following were laid on the table:—

Auckland Institute for the year ending 31st March, 1941.
Wellington Branch for the year ending 30th September, 1941.
Canterbury Branch for the year ending 31st October, 1941.
Otago Branch for the year ending 31st October, 1941.
Nelson Institute for the year ending 31st December, 1941.
Southland Branch for the year ending 31st March, 1942.

Mr. Hudson stated that the reason that the Hawke's Bay Branch had not forwarded its report was that its Honorary Secretary had recently died.

Standing Committee's Report: On the motion of Mr. Eliott, seconded by Dr. Marshall, the report was taken as read. On the motion of Dr. Allan, seconded by Dr. Turner, the report was adopted:

REPORT OF THE STANDING COMMITTEE FOR THE YEAR ENDING 31ST MARCH, 1942.

Meetings: Six meetings of the Standing Committee were held during the year, the attendance being as follows:—The President, Dr. G. Archey, Auckland, 1; Dr. H. H. Allan, Vice-president, Wellington, 6; Mr. B. C. Aston, Wellington, 6; Dr. L. Bastings, Wellington, 4; Mr. G. V. Hudson, Wellington, 6; Dr. E. Marsden, Wellington, 1; Dr. P. Marshall, Wellington, 4; Dr. W. R. B. Oliver, Wellington, 6.

The Council: Professor W. P. Evans retired from the Vice-Presidency at the last Annual Meeting, and at the meeting of the Standing Committee on the 6th June, Dr. Allan proposed the following resolution, which was carried by acclamation:—

> That the Standing Committee records its deep appreciation of the services rendered by Professor Evans during the period of six years in which he presided over its meetings and zealously cared for the welfare of the Society.

Professor Evans thanked the Standing Committee for the expression of its appreciation.

Sir Thomas Easterfield: At the same meeting the following resolution was moved by Mr. Aston and carried:—

> On the resignation of Sir Thomas Easterfield from the Council of the Royal Society of New Zealand the Society desires to place on record an appreciation of his services in the promotion of knowledge in the science of chemistry for the past forty years. During this period he has been a member or officer of the Society, serving on the Council since 1903, being awarded the Hector Medal in 1913, elected an Original Fellow in 1919, and President in 1920. His special knowledge and skill in chemistry have been of great service to the Dominion both in peace and war. His kindly nature and enthusiasm for new knowledge has always been an inspiration to his students and fellow workers. The Council much regrets his recent illness and hopes for an early recovery.

Mr. B. C. Aston and Dr. W. R. B. Oliver have been appointed for a further term as Government representatives on the Council.

The following changes on the Council have been notified by Member Bodies: Auckland Institute: As Dr. Archey, by virtue of his office as President, has a seat on the Council, Mr. A. T. Pycroft was elected to represent the Auckland Institute together with Professor Segar. Wellington Branch: Dr. L. I. Grange replaces Dr. L. Bastings as representative of the Wellington Branch.

Publication Matters: The Hon. Editor, Dr. J. Marwick, has attended meetings of the Standing Committee when publication matters have been under discussion. Volume 70, Part 4, and Volume 71, Parts 1, 2, and 3 have been published, and the last Part of Volume 71 is almost ready for distribution.

Owing to the increased cost of printing, it was considered necessary to enforce certain restrictions on the length of papers submitted for publication. On the 13th August the Standing Committee resolved to restrict papers to

20 pages. At a later date (23rd February), this resolution was amended as follows: "That in future papers for the *Transactions* be restricted in length so that the total cost of text and plates shall not exceed £20 each paper."

The following "Notice to Authors" drafted by the Vice-President was approved for circulation to authors and for insertion in the *Transactions*:—

1. Until further notice no paper the estimated cost of which exceeds £20 for text and plates will be accepted. Authors should, therefore, be as concise as possible; introductions, references to published work, discussions and summaries should be brief and to the point; only essential figures and tables should be included.
2. Papers not fully following the "Instructions to Authors" given in the *Transactions*, Vol. 67, Part 1, 1937, will be returned to the authors for revision or re-drafting. Authors should not pass on their responsibilities to the editors.
3. Citations must be in the form prescribed, properly arranged and punctuated.
4. Referees will report not only on the general suitability of the paper for publication, but will suggest where condensation or excision is required.
5. Papers will, in general, be published in order of priority of final acceptance.

The following resolution was received from the Otago Branch and referred to the Annual Meeting:—

"That in the opinion of the Council of the Otago Branch, in the event of its being necessary, owing to shortage of paper, financial, or other reasons, to cut down the *Transactions*, the abstracts of papers should be replaced by lists of titles of papers.

Obituary Notices: It was decided to publish Obituary Notices of the late Sir Arthur Hill and the late Mr. R. M. Laing. Dr. H. H. Allan and Mr. C. E. Foweraker undertook to write the notices respectively.

Library: Presentations: A complete set of *Discovery* Reports has been presented to the Library by the *Discovery* Committee, and Professor W. P. Evans has presented an almost complete set of *Fuel, in Science and Practice*, and two books, *Trees from Other Lands—Eucalypts in New Zealand*, by J. H. Simmonds, and a biography of the late Lord Rutherford, by A. S. Eve.

On the death of Mr. R. M. Laing, books on Algae purchased by him under a research grant were handed over to the Society's Library in accordance with the rules governing research property, and already these have been in demand.

Exchanges: No new exchanges have been added, but two or three applications are under consideration by the Library Committee. Owing to the spread of the war, practically every one of our foreign exchanges has now come under the ban of "communications suspended," and the *Transactions* set aside for distribution to these countries after the war are steadily increasing.

Binding: Approximately 35 volumes were bound during the year, and the balance in the Library Binding Fund is rapidly diminishing. Unless a grant for binding can be obtained, it will be advisable to conserve the balance for binding current numbers of series that have been bound to date.

Member Bodies: The annual reports and balance sheets have been received from Member Bodies as follows:—

Auckland Institute for the year ending 31st March, 1941.
Wellington Branch for the year ending 30th September, 1941.
Canterbury Branch for the year ending 31st October, 1941.
Otago Branch for the year ending 31st October, 1941.
Nelson Institute for the year ending 31st December, 1941.
Southland Branch for the year ending 31st March, 1942.

Fellowship R.S.N.Z.: Dr. R. A. Falla was gazetted a Fellow of the Royal Society of New Zealand on the 3rd July, 1941.

On the 8th September Member Bodies were advised of the vacancies occurring in the Fellowship and were asked to submit nominations. Ten nominations were received and were forwarded to the Fellows for selection.

Subsequently the Fellowship Selection Committee considered the voting papers and forwarded its recommendation for consideration at the Annual Meeting.

Hon. Membership: Only three nominations have been received from Member Bodies to fill the vacancy caused by the death of Sir James Frazer. The election will take place at the Annual Meeting in May.

At a meeting of the Standing Committee held on the 18th November, Dr. Allan moved the following resolution in reference to the death of Sir Arthur W. Hill:—

> That the Royal Society of New Zealand place on record its profound regret at the death of Sir Arthur W. Hill, Director of the Royal Botanic Gardens, Kew.
>
> Sir Arthur splendidly carried on the tradition of cordial co-operation with and assistance to the botanists of the Dominions that had been created by Sir J. D. Hooker. Also, directly, he published a number of valuable papers on New Zealand plants. His visit to New Zealand in January, 1928, will be remembered not only for his official activities, but also for his encouragement of and advice to the younger botanists he met. His "Report on Matters of Botanical Interest in New Zealand" has greatly influenced botanical progress in this country. Visitors to Kew from the Dominions will not easily forget his hospitality and his efforts to give them fullest facilities for their work. By his death the Royal Society has lost one of its most distinguished Honorary Members and a true friend. Its members desire to convey to his colleagues their regret at the loss of a great chief, and to his relatives their heartfelt sympathy.

Hector Award: The presentation of the Hector Medal and Prize to Dr. H. J. Finlay took place at a general meeting of the Wellington Branch on the 25th June. Dr. Archey, President of the Society, attended and made the presentation.

Hutton Award: At the same meeting the President also presented the Hutton Medal to Dr. H. H. Allan for his botanical researches.

As a result of suggestions made at the last Annual Meeting, consideration was given by the Standing Committee to the Rules governing the award of the Hutton Medal. It was decided to recommend to the Annual Meeting that there should be an additional rule defining the constitution of the Committee of Award and providing that

(1) The Committee shall consist of three holders of the Award.

(2) The Committee shall meet at least once, and the cost of the meeting shall be a charge on the Hutton Fund.

The Standing Committee further recommended the desirability of appointing to the Committee a recipient of the medal in each of the three sciences concerned.

Hutton Grants: An application from Mr. L. E. Richdale for £40 for ornithological research at Stewart Island was recommended to the annual meeting for approval. An application from Dr. S. N. Slater for £40 for an investigation on the nature of the physiologically active material—phthioic acid—obtained from tubercle bacillus was not recommended, as it was considered outside the scope of a Hutton grant.

An application from Dr. F. J. Turner that he be allowed to utilise the unexpended balance of his Hutton Grant in paying the excess cost in the publication of his paper "Petrofabric Studies on Oriented Sections of Peridotites and Allied Rocks from New Zealand" was granted.

T. K. Sidey Summer-time Rules: The amended report of the Sub-committee set up to consider the rules governing the award of the T. K. Sidey Summer-time Medal and Prize has been circulated to members for consideration.

Loder Cup: The Society nominated Mr. Norman Potts, of Opotiki, for the 1941 Loder Cup Award. The Loder Cup Committee made the award to Mr. E. Earle Vaile, of Auckland.

Science Teaching in Schools: In the terms of the resolution passed at the last Annual Meeting, the attention of the Hon. Minister of Education was drawn to the need for improvement in the teaching of science in post-primary schools. The Hon. Minister replied that the matter would receive his attention.

Soil Erosion: On the passing of the Soil Conservation and Rivers Control Act the President and Dr. Oliver, Convener of the Wild Life Control Committee forwarded to the Hon. Minister of Public Works a letter expressing the Society's gratification at the measure and the fact that research and investigation had been given a prominent place in the functions of the Control Council, and offered to give any assistance within the scope of the Society in this important national undertaking. The Minister replied thanking the President for his

assurance of help, stating that the Soil Conservation Council would appreciate the value of the Society's offer.

Theses: Arising out of a discussion on the length of papers published in the *Transactions*, it was resolved, on the suggestion of the President, to advise the University of New Zealand of the Society's inability to publish theses in full and recommend for acceptance a full MS. thesis together with a reduced published account of the results and findings of the research. The Senate of the University of New Zealand considered this resolution at its meeting in January, 1942, and the following reply was received from the Registrar:—

> In reply to your letter of the 24th November as to the costs of publishing theses for Doctorates, the Senate has now resolved: That in determining special circumstances to be approved by the Chancellor under Clause IV of the Statute D.Sc., the Chancellor be asked in cases where the essential portions of a thesis submitted by a candidate have been accepted for publication by an approved scientific body to give consideration to that fact.

Insurances: In view of the increased war risk, attention was drawn to the advisability of increasing the amount of insurance cover on the Society's property, and the Hon. Treasurer was given authority to increase up to 50%. At the Hon. Treasurer's request, the Secretary made a detailed valuation of the Library and stocks of publications as follows:—

Library	£10,269	4	0
Stack Room	1,323	8	0
Stock in Stack Room	2,389	9	6
Stock in Store Room	11,188	3	0
Carter Library ..	500	0	0
Furniture	48	0	0

Accordingly the Hon. Treasurer recommended that the insurance be increased from £2500 to £5540, and this recommendation was adopted by the Standing Committee on the 9th April, 1942.

Endowment Fund: During the year accrued interest in the Endowment Fund to the amount of £300 was invested in National Development Loans Stock at 3¼%, maturing 1956-59.

Signatures: On the 11th June it was resolved that two of the three following should sign the Society's cheques:—

Mr. M. A. Eliott, Dr. H. H. Allan, Mr. B. C. Aston.

Arising therefrom:—

Publication Matters: Consideration was given to a resolution of the Otago Branch as follows: "That if curtailment of the *Transactions* was found to be necessary, the abstracts of papers be replaced by lists of titles of papers." Dr. Turner said the analysis of pages submitted by the Hon. Editor in his report showed that the saving effected by the resolution would be a very small amount. Professor Evans stated that the reintroduction into the *Transactions* of the reports and abstracts had been welcomed by Member Bodies, and he thought the small economy suggested was not warranted. Dr. Hilgendorf stated that he had recently had occasion to refer to the Proceedings and abstracts in early numbers of the *Transactions*, and he found there a great deal of historical interest and information.

After some further discussion, the President moved, Dr. Allan seconded, and it was carried: "That if papers are to be published elsewhere, they be referred to by title only, but otherwise an abstract of the paper be printed in the *Transactions*."

Hutton Award Regulations: On the motion of Dr. Turner, seconded by Mr. Hudson, it was resolved: "That the Council approves of the principle of a Committee to make recommendations on the Hutton Award and that the Committee consist if possible of

three holders of the award including a representative of each of the three sciences concerned. The Committee to meet once, the cost thereof to be a charge on the Hutton Fund."

Lunch Adjournment: The meeting adjourned for lunch, the visiting members being the guests of the local members.

Roll Call: The afternoon roll call was the same as the morning call.

Hutton Grants: On the recommendation of the Standing Committee, Mr. L. E. Richdale was granted £40 for ornithological research at Stewart Island, and Dr. F. J. Turner £25 for structural petrology of metamorphic rocks. (Dr. Turner applied in 1940 for £50 for this research, £25 being recommended to the 1941 Annual Meeting, the balance to be recommended to the 1942 Annual Meeting.)

Hon. Treasurer's Report: Mr. Eliott moved the adoption of his report, the balance sheets and statements of accounts; seconded by Mr. Pycroft and carried.

Report of the Hon. Treasurer.

The statement of Assets and Liabilities shows a balance of Assets £664 5s 4d, as compared with £728 9s 9d last year. Receipts of Levy on Vol. 70 are £35 less than those for Vol. 69. (An amount received after the books were closed reduces the difference to £25 10s.) Sales of publications are £40 less than last year.

The cost of printing the *Transactions* is substantially the same, viz., £631 17s 8d, against £627 4s 1d last year. It is satisfactory to record that the Standing Committee has decided to restrict the length of papers so that the total cost of text and plates in any one paper shall not exceed £20.

During the past year the question of increased insurance including war risk arose, and it became necessary to arrive at an estimate of the value of the Society's stocks, i.e., Library, *Transactions*, and other publications, furniture, etc. It will be noted that for the first time this information appears on the balance sheet. Necessarily this must be only a very rough estimate—it is impossible to determine the actual intrinsic value, as the usual methods based on a commercial value would not apply. However, total insurances including war risk have now been increased from £2,500 to £5,540, but even this is only about 20% of the estimated value of the stock, whereas up to 80%, or more, would be the ratio on commercial stocks.

The Endowment Fund now stands at £2,011, an increase of £136 over last year. As this Fund has reached £2,000, the question arises as to the advisability of, say, half the annual interest being used for binding purposes. Only £39 17s 10d is left in the Binding Fund, and it is important to get as much binding done as possible.

The Trust Funds remain in much the same position as last year.

I desire once again to commend the Secretary on the way the books and accounts have been kept.

Report on Member Bodies.

Member Body.	Members.	Income.	Expenditure.	Rule 3.
Auckland Institute	573	7,906 19 1	8,698 19 7	Library, Museum Levy
Wellington Branch	222	189 7 5	162 6 2	Library and Levy
Canterbury Branch	126	139 1 0	136 12 1	Library and Levy
Otago Branch	173	307 3 0	320 10 8	Levy
Nelson Institute		1,317 8 7	1,382 12 3	Library
Nelson Philosophical Soc.	28	14 14 6	18 3 10	Levy
Southland Branch	46	49 19 0	44 14 7	Museum and Levy
Hawke's Bay Branch	No reports or balance sheets.			
Manawatu Branch	No reports or balance sheets.			

M. A. Eliott, *Hon. Treasurer.*

STATEMENT OF RECEIPTS AND PAYMENTS FOR THE YEAR ENDING MARCH 31, 1942.

Receipts.	£	s.	d.	*Payments.*	£	s.	d.
Balance as at 31st March, 1941	1,159	18	3	Otago Daily Times—Vol. 70 (4), 71 (1, 2, 3)	631	17	8
Annual Grant	750	0	0	Stationery	2	16	4
Levy, Vol. 70, *Transactions R.S.N.Z.*	175	10	0	Salary	325	0	0
Sales of Publications	41	6	5	Binding, Library Books	29	10	0
Travelling Expenses: Member Bodies' Share	26	10	0	Travelling Expenses, Members of Council	47	14	5
Interest on P.O.S.B. Account	26	9	7	Petty Cash (Secretary, Editor, Vice-President)	17	13	4
Endowment Fund Interest	69	8	5	Charges (Insurance Prem., Audit, Telephone)	28	0	7
Hector Memorial Fund Interest	53	2	3	Hutton Grant Instalments	22	10	0
Hutton Memorial Fund Interest	68	8	6	Hector Prize	50	0	0
T. K. Sidey Summer-time Fund Interest	23	2	6	Engraving Hector and Hutton Medals	0	15	0
Carter Library Legacy Interest	7	18	3	Advertisement *re* Presentation of Medals	0	14	6
Hamilton Memorial Fund Interest	2	3	2	Endowment Fund: Interest Invested	291	15	0
Cockayne Memorial Fund Interest	11	6	7	Trust Funds paid direct to P.O.S.B. Accounts	10	5	6
Cockayne Memorial Fund Contribution	1	4	3	Balance as Under	148	17	6
Favourable Exchange	2	3	7	Adjustments between Trust Accounts and Bank of N.Z.	889	16	5
Adjustments between Trust Accounts and Bank of N.Z.	78	14	6				
	£2,497	6	3		£2,497	6	3

Balance at Bank of N.Z.		£174 1 10	
Less unpaid cheques	10 17 7		
	10 5 6		
		21 3 1	
		£152 18 9	
Post Office Savings Bank		731 13 7	
Petty Cash in Hand		5 4 1	
			£889 16 5

STATEMENT OF LIABILITIES AND ASSETS AT MARCH 31, 1942.

Liabilities.	£	s.	d.	*Assets.*	£	s.	d.
Hector Memorial Fund Capital Account	1,184	18	1	Inscribed Stock	5,468	2	6
Hector Memorial Fund Revenue Account	82	7	5	Bank of New Zealand	152	18	9
Hutton Memorial Fund Capital Account	1,506	8	6	Post Office Savings Bank	731	13	7
Hutton Memorial Fund Revenue Account	255	1	4	Petty Cash in Hand	5	4	1
Sidey Summer-time Fund Capital Account	529	13	4	Sundry Debtors	73	9	1
Sidey Summer-time Fund Revenue Account	92	16	6	Hector Memorial Fund P.O.S. Bank	82	7	5
Cockayne Memorial Fund Capital Account	249	12	0	Hutton Memorial Fund P.O.S. Bank	255	1	4
Cockayne Memorial Fund Revenue Account	54	13	1	Sidey Summer-time Fund P.O.S. Bank	122	7	4
Hamilton Memorial Fund Capital Account	69	13	7	Cockayne Memorial Fund P.O.S. Bank	54	13	1
Hamilton Memorial Fund Revenue Account	4	5	9	Hamilton Memorial Fund P.O.S. Bank	73	19	4
Carter Library Legacy Capital Account	162	19	0	Carter Library Legacy P.O.S. Bank	0	16	5
Endowment Fund Capital Account	1,864	2	5	Carter Library Legacy, owed to R.S.N.Z.	9	7	8
Endowment Fund Revenue Account	147	5	11				
Library Fund	39	17	10				
Research Grants Fund	122	0	6				
Balance of Assets over Liabilities	664	5	4				
	£7030	0	7		£7,030	0	7

M. A. ELIOTT, *Hon. Treasurer.*

The Audit Office having examined the balance sheet and accompanying accounts required by law to be audited, hereby certifies them to be correct.

CYRIL COLLINS, *Controller and Auditor-General.*

REVENUE ACCOUNT FOR THE YEAR ENDING MARCH 31, 1942.

Expenditure.	£	s.	d.	*Income.*	£	s.	d.
To Printing Trans. Vol. 70 (4), 71 (1, 2, 3)	611	9	2	By Balance	728	9	9
" Stationery	2	16	4	" Annual Grant	750	0	0
" Salary	325	0	0	" Levy	185	0	0
" Petty Cash—				" Sales of Publications	39	14	9
Secretary	13	2	8	" Trust Funds Administration Expenses	5	0	0
Hon. Editor	3	7	0				
Vice-President, 1940-41	1	3	8				
" Travelling Expenses, Society's Share	21	4	5				
" Charges (Audit, Insurance, Telephone, Bank)	24	9	6				
" Sales credited to Endowment Fund	41	6	5				
" Balance	664	5	4				
	£1,708	4	6		£1,708	4	6

By Balance £664 5 4

TRUST ACCOUNTS FOR THE YEAR ENDING MARCH 31, 1942.

Hector Memorial Fund.

Dr.	£	s.	d.	*Cr.*	£	s.	d.
To Hector Prize	50	0	0	By Capital Invested ..	1,184	18	1
" Audit Fee	0	5	0	" Balance Revenue Account 31/3/41	81	5	11
" Engraving Medal ..	0	8	6	" Interest	53	2	3
" Advertisements ..	0	7	3				
" Administration Exs.	1	0	0				
" Balance	1,267	5	6				
	£1,319	6	3		£1319	6	3
				By Balance	£1267	5	6

Hutton Memorial Fund.

Dr.	£	s.	d.	*Cr.*	£	s.	d.
To Grants	22	10	0	By Capital Invested ..	1,506	8	6
" Audit Fee	0	5	0	" Balance Revenue Account 31/3/41 ..	211	1	7
" Engraving Medal ..	0	6	6	" Interest	68	8	6
" Advertisements ..	0	7	3				
" Administration Exs.	1	0	0				
" Balance	1,761	9	10				
	£1,785	18	7		£1,785	18	7
				By Balance	£1,761	9	10

T. K. Sidey Summer-time Fund.

Dr.	£	s.	d.	*Cr.*	£	s.	d.
To Audit Fee	0	5	0	By Capital Invested ..	500	0	0
" Administration Exs.	1	0	0	" Interest added to Capital	29	13	4
" 1/10th Interest to Capital	2	6	3	" Balance Revenue Account 31/3/41 ..	73	5	3
" Balance	622	9	10	" Interest	23	2	6
	£626	1	1		£626	1	1
				By Balance	£622	9	10

Hamilton Memorial Fund.

Dr.	£	s.	d.	*Cr.*	£	s.	d.
To Audit Fee	0	2	6	By Capital	48	7	11
" Administration Exs.	0	2	6	" Interest added to Capital	21	5	8
" Half Interest to Capital	1	1	7	" Balance Revenue Account 31/3/41 ..	3	9	2
" Balance	73	19	4	" Interest	2	3	2
	£75	5	11		£75	5	11
				By Balance	£73	19	4

Carter Library Legacy.

Dr.	£	s.	d.	Cr.	£	s.	d.
To Revenue Account 31/3/41	16	10	11	By Capital	162	19	0
" Audit Fee	0	5	0	" Interest	7	18	3
" Administration Exs.	0	10	0	" Loan from R.S.N.Z. (£18 4s 1d), repaid £8	10	4	1
" Balance	163	15	5				
	£181	1	4		£181	1	4
				By Balance	£163	15	5

Cockayne Memorial Fund.

Dr.	£	s.	d.	Cr.	£	s.	d.
To Administration Exs.	0	2	6	By Capital Account ..	249	12	0
" Balance	304	5	1	" Balance Revenue Account 31/3/41 ..	42	4	9
				" Interest	11	6	7
				" Contribution	1	4	3
	£304	7	7		£304	7	7
				By Balance	£304	5	1

Endowment Fund.

Dr.	£	s.	d.	Cr.	£	s.	d.
To Interest Invested ..	291	15	0	By Capital Invested ..	1,864	2	5
" Audit Fee	0	5	0	" Balance Revenue Account 31/3/41 ..	303	6	6
" Administration Exs.	1	5	0	" Interest	69	8	5
" Balance	2,011	8	4	" Interest from General Account	26	9	7
				" Sales of publications	41	6	5
	£2,304	13	4		£2,304	13	4
				By Balance	£2,011	8	4

Mr. Eliott drew attention to the fact that the amount of the insurance on the library and stocks had been increased. Mr. Aston objected to the amount put down as the valuation of the stock, and moved that in future the Hon. Treasurer's report and balance sheets be placed before the Standing Committee for approval before circulation to members. Mr. Eliott said that his report was to the Council, not the Standing Committee. It was pointed out that the Standing Committee had previously adopted the report containing the figures mentioned. Mr. Aston's motion was not seconded and lapsed.

On the motion of Dr. Marshall, a sub-committee consisting of Mr. Aston and Professor Evans advise the Standing Committee regarding any necessary adjustment of valuation and insurance.

Mr. Eliott moved that half the amount of this year's interest in the Endowment Fund be devoted to binding periodicals in the Library. Professor Evans seconded the motion. Mr. Aston objected to the interest in the Endowment Fund being utilised in this way, stating that the Fund should be allowed to grow, and he moved as

an amendment that the matter be referred to the Standing Commitee to find the amount required for binding from other sources. This amendment was carried, and it was further recommended to the Standing Committee to ensure that £50 be spent on binding in the coming year.

Hon. Editor's Report: On the motion of Mr. Hudson, the report of the Honorary Editor was adopted.

REPORT OF HONORARY EDITOR.

During the year ended 31st March, 1942, the four parts of *Transactions*, Volume 71, comprising 383 pages and 52 plates, have been published. This is 101 pages and 21 plates less than last year's volume—a reduction of 21% and 29% respectively.

Volume 71 consists of the following:—

Subject.	Number of Papers.	Pages.	Plates.
Astronomy	1	4	—
Botany	4	42	3
Chemistry	1	2	table
Geology	11	160	22
Palaeontology	3	45	10
Physics	1	23	2
Seismology	1	3	—
Zoology	11	45	15
Abstracts	15	9	—
Proceedings		37	—
Appendix		8	—
Index		5	—

The following manuscripts have been handled during the year:—

Manuscripts in hand from preceding year (including 9 printed in Vol. 71, Part 1)	17
MSS. received 1/4/41–31/3/42	30
	47
Manuscripts printed in Volume 71	33
Manuscripts in hand, including 7 for 72 (1) ..	10
Manuscripts held in suspense pending overseas refereeing	1
Manuscripts withdrawn by authors	2
Manuscripts declined (adverse referee's report)	1
	47

The average time between the receipt of papers as finally approved and their date of publication has been seven months, an increase of half a month compared with the preceding year. The longest period has been 14 months.

The Editor is greatly indebted for help to Dr. C. O. Hutton, Associate Editor, and to a number of painstaking referees.

J. MARWICK, *Honorary Editor.*

Mr. Hudson spoke of the great amount of painstaking service and time devoted by Dr. Marwick in his office of Honorary Editor, and he doubted if the Society appreciated sufficiently the work that Dr. Marwick did. On the motion of Mr. Hudson, seconded by the President, it was resolved that a letter be sent to Dr. Marwick conveying the most cordial thanks of the Society and its appreciation of his services.

Hon. Librarian's Report: Professor Evans moved the adoption of his report. Seconded by Mr. Pycroft and carried.

REPORT OF HONORARY LIBRARIAN.

The Library continues to be of use to the members of the Society and the Staff and Honours Students of Victoria University College. Approximately 200 volumes were taken out by workers during the year in addition to those consulted in the Library, and a number of volumes have been posted to other centres under the inter-loan scheme.

At the request of the Libraries Association an article dealing with the history of the Royal Society's Library was written by the Secretary and published in the November issue of the Bulletin of the New Zealand Library Association.

Binding: During the year 35 volumes were bound, and the small amount now left in the Binding Account will be adequate to keep only the binding of a few sets up-to-date. It will be most unfortunate if the present binding arrangements cannot continue.

Exchanges: The exchanges from Britain, America, South Africa, and Australia come to hand more or less regularly, and the Society is fortunate in having lost very few periodicals by enemy action.

W. P. EVANS, *Honorary Librarian.*

National Art Gallery and Dominion Museum: On the motion of Professor Evans, seconded by Dr. Marshall, the report of the representatives on the Board of Trustees of the National Art Gallery and Dominion Museum was adopted.

NATIONAL ART GALLERY AND DOMINION MUSEUM BOARD OF TRUSTEES.

Report of Society's Representatives.

The Board of Trustees met four times during the year ending 31st March, 1942, and the Society was represented at each meeting.

War conditions have again resulted in a slight decrease in the sum of money available for carrying on the work of the Art Gallery and Museum, but in each institution a satisfactory year's work has been completed.

Early this year the Art Gallery had to give up all the space in the west wing and the tea-room for use by the military authorities, and now the whole of the east wing is also being handed over.

Many of the more valuable pictures belonging to the National Gallery have been sent for safe keeping to an inland town, where they are being kept housed in a ferro-concrete building belonging to the Public Trust Department. A large part of the asphalted basement of the Museum has also been placed at the disposal of the Gallery for storage of pictures.

Arrangements have been made for the necessary fire-watching and E.P.S. services, and a warden's post and a first-aid room are now being fitted in the Museum.

W. P. EVANS.
P. MARSHALL.

Royal New Zealand Institute of Horticulture: On the motion of Dr. Oliver, seconded by Dr. Allan, the report of the representative on the Royal New Zealand Institute of Horticulture was adopted.

THE ROYAL NEW ZEALAND INSTITUTE OF HORTICULTURE.

Report of Representative.

Annual Conference: Arrangements for the holding of the nineteenth annual conference of the Institute in conjunction with National Horticultural Week at Hastings, in February, 1942, were well in hand, when, in December, 1941, war with Japan broke out. Accordingly, National Week was abandoned; but it was decided to hold the conference in Wellington in February.

The principal remits of general interest carried at the conference held on February 26, 1942, were as follows:—

That the necessity for the establishment of a School of Horticulture be again impressed on the Government.

That the Institute commends to its members and the public generally the work being done by the Native Plant Preservation Society to prevent the extermination of rare native plants.

Conference also approved of remits passed at the Electric Power Board's and Supply Authorities' Conference relative to the kinds of trees most suitable for growing near public roads or telephone lines.

Historic Trees: A Committee was set up to go into the question of preserving historic and other trees of interest. The Committee interviewed the Under-Secretary of Internal Affairs. As a result, it was decided that Dr. H. H. Allan continue his investigation into the historic trees of New Zealand, with a view to a list being published and circulated to local authorities and others.

W. R. B. OLIVER.

Observatories' Committee: On the motion of Professor Segar, seconded by Mr. Eliott, the report of the representatives on the Observatories' Committee was adopted.

OBSERVATORIES COMMITTEE.

Report of Society's Representative.

There is nothing to report except the fact that the Observatories Committee has not met during the past two years. Reports have been received showing that satisfactory work is being carried out in the Observatories. The responsibility for calling meetings rests with Head Office, and evidently no necessity has arisen. Personally, I think that an annual meeting is desirable so that contact may be made with the Directors.

D. C. H. FLORANCE, *Chairman Observatories Committee.*

Carter Observatory Board: On the motion of Mr. Pycroft, seconded by Dr. Hilgendorf, the report of the representatives of the Society on the Carter Observatory Board was adopted, and it was resolved that the photograph of the newly-opened Observatory be printed in the *Transactions* together with a short account of the Carter Observatory.

CARTER OBSERVATORY BOARD.

Report of Society's Representatives.

There has been no change in the constitution of the Carter Observatory Board since our last report, and a further eight meetings have been held.

The construction of the new Observatory has been completed and the rooms furnished. Several months were spent by the Observatory staff in overhauling, cleaning, and painting the 9-inch telescope and, although much fine adjustment is still necessary on the instrument, it is already in working order. It has not yet been possible for the staff to devote the necessary time to put the spectrohelioscope into operation. There is little chance of being able to proceed with the mounting of the 20-inch telescope until after the war.

The Observatory Library has been augmented by a valuable gift from Dr. L. J. Comrie, London, of fourteen cases of books consisting for the most part of the private libraries of the late Dr. A. C. D. Crommelin and Mr. H. P. Hollis, both formerly of the Greenwich Observatory. With the addition of the Dominion Observatory astronomical library, which has been transferred to the new building, the present Library is very well stocked and should prove to be a most valuable source of astronomical information.

The temporary Observatory building, which had existed since 1924 and was known, prior to its being handed over to the Board, as the Wellington City Observatory, was demolished early in December, 1941.

Adequate insurances, including war risk insurance, have been taken out for the new building and its furnishings.

On the 20th December, 1941, the Carter Observatory was officially opened by the Right Honourable the Prime Minister, Mr. P. Fraser, P.C., when he unveiled the memorial plaque, which reads:

Dedicated
To the Memory of
CHARLES ROOKING CARTER
1822–1896
Through whose generosity
The Erection of this Building
Was made Possible.

At the same ceremony, His Worship the Mayor, Mr. T. C. A. Hislop, on behalf of the City Council, formally handed over the 9-inch telescope and the Observatory grounds to the Board.

The work of the Observatory, covering a wide field, has been carried on as usual, despite the handicaps presented in transferring to the new building. Solar observations are made regularly, and auroral reports are gathered from nearly 600 established observers in New Zealand, as well as many sources in Tasmania. This auroral organisation provides valuable data for statistical purposes, especially in the study of correlations. Double stars, occultations and comets are observed. The results of the routine observations are published in the Carter Observatory Astronomical Bulletin, which appears regularly. Papers prepared by the Observatory staff have also appeared in various scientific journals and reprints have been issued.

A series of lectures was given in 1941 by Mr. Geddes, and the temporary Observatory was open to the public until November, 1941. In March, 1942, the public sessions were again resumed, with much success, in the new building.

On 13th December, 1941, Mr. M. Geddes left for service with the Royal New Zealand Navy. Mr. I. L. Thomsen was appointed Acting-Director, and Miss K. Turner was appointed as clerical assistant.

M. A. F. BARNETT
C. G. G. BERRY.

CARTER OBSERVATORY.

In 1896 Charles Rooking Carter bequeathed to the Royal Society of New Zealand (then the New Zealand Institute) the residue of his estate amounting to approximately £2240, to form "the nucleus of a fund for the erection in or near Wellington of an astronomical observatory fitted with telescope and other instruments and the endowment of a professor and staff."

This fund was invested by the Society to the best advantage and allowed to accumulate, and although many attempts were made in astronomical circles to have it utilised, the Society did not deviate from its policy of allowing it to grow until it was large enough to enable the testator's expressed wishes to be carried out.

In March, 1937, the Bequest had reached a sum of £12,402 and representations were again made by interested bodies, this time to the Government, that the Bequest should be utilised. Several conferences were held between the Society, the Government, and the City Council, and a Carter Bequest Committee was set up. It was agreed that a scheme be drawn up whereby an observatory should be built in Wellington out of the Carter Bequest, and that its maintenance should be the responsibility of the Government and the City Council. The latter agreed to give the land on which the Observatory should be built.

The Carter Bequest Committee set up a technical sub-committee to report on a suitable scheme for building and equipping the observatory and its cost. This committee consulted with overseas astronomical authorities and submitted a report which provided for an expenditure of £6250 on the building and equipment.

The recommendations of the Carter Bequest Committee, together with the report of the above sub-committee, were fully considered at the annual meeting

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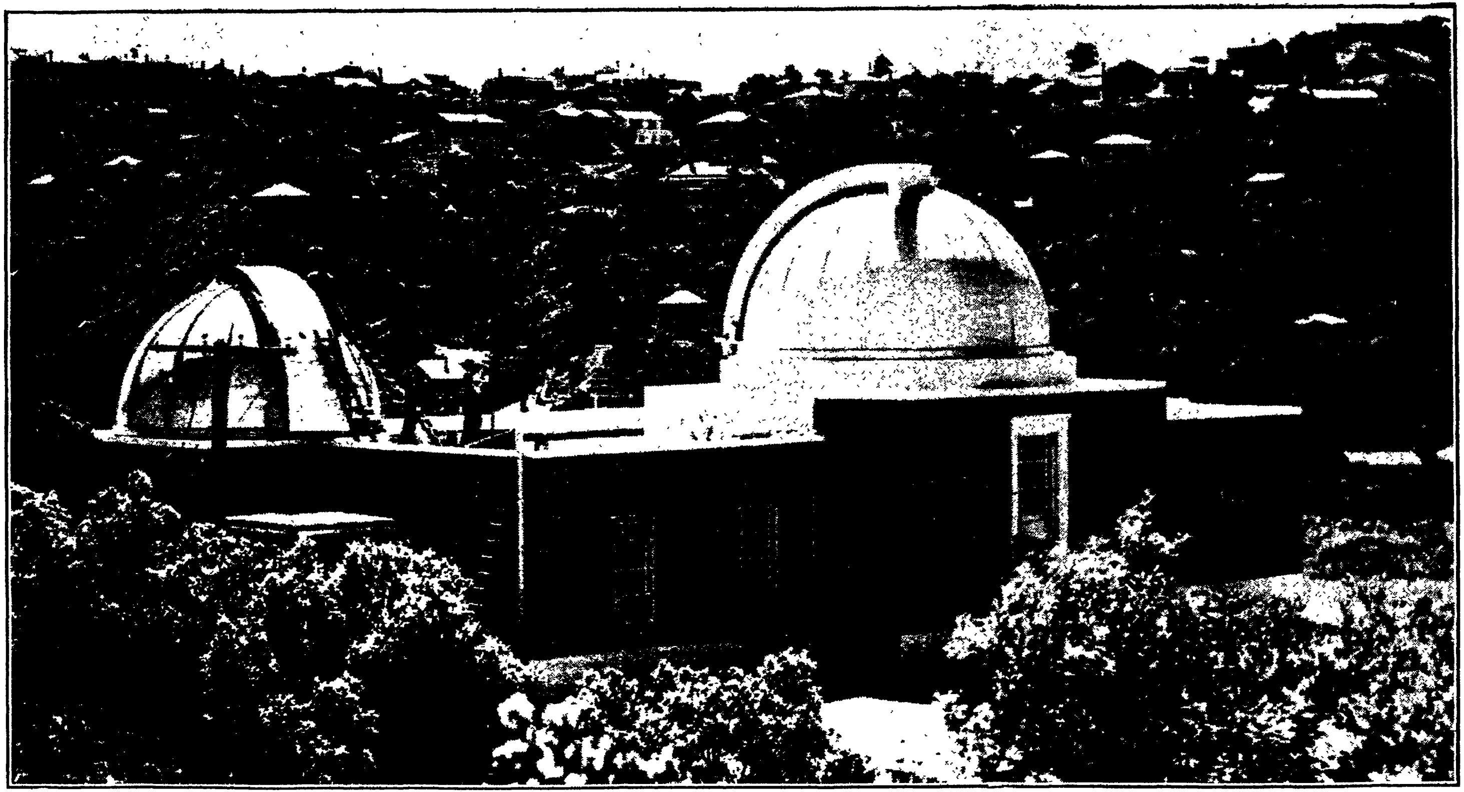


CARTER OBSERVATORY, KELBURN, WELLINGTON. Courtesy "Evening Post," Wellington.

of the Council of the Royal Society held on the 27th May, 1937, and finally the following resolution was carried:—

> That the Council of the Royal Society of New Zealand approves of the suggestions made by the Committee set up to consider the utilisation of the Carter Bequest as set forth in the letter dated May 3, 1937, from the Under-Secretary of Internal Affairs and, subject to the necessary legislative authority being received, instructs the Standing Committee to transfer the accumulated funds belonging to the Carter Bequest to the proposed Statutory Board of Trustees as soon as it is satisfied that the sum necessary for service and upkeep of the proposed Carter Observatory, viz., £1000 per annum, is definitely assured.
>
> The Council of the Royal Society, however, is of opinion that the sum to be contributed annually by the Wellington City Council, viz., £250, ought not to be subject to an annual vote, but should be made obligatory by the Empowering Act.

The Carter Observatory Act, embodying proposals approved by the Council, was passed on the 14th September, 1938. It provided for a Carter Observatory Board, comprising two representatives of the Royal Society, two representatives of the City Council, and five appointed by the Government. On the 29th October, Dr E. Kidson and Mr C. G. G. Berry were appointed to represent the Royal Society, and on the death of Dr. Kidson in June, 1939, Dr. M. A. F. Barnett was appointed to succeed him on the Board.

As reported in the annual report to the Council of the Society's representatives printed above, the Observatory was completed and opened by the Right Honourable the Prime Minister, Mr Peter Fraser, P.C., on 20th December, 1941.

Research Grants: The reports of research grantees were adopted.

Reports of Research Grantees.

Professor J. Marples, who obtained a grant of £20 from the Society in 1938 for research on the Little Owl, has reported that the greater part of the grant has been spent on a study of the food of the Little Owl. A report of this is almost completed and should be ready for publication in a few weeks' time. The remainder of the grant was to be expended on a visit to Green Island, off the Otago coast, for the purpose of carrying out a faunal survey. All preparations were completed for this visit when the entry of Japan into the war and the consequent likelihood of restrictions and emergency regulations seemed to make it advisable to postpone the trip. Professor Marples wishes to request that the balance of the grant (£5) be held over until such time as it may be possible to visit the island.

Dr. G. H. Uttley, who in 1928 was granted £35 for micrographic apparatus for research on Bryozoa, has reported that he is still engaged on collecting, classifying and describing both Recent and fossil Bryozoa. He will not require the balance of the grant (£6 11s 2d), but he wishes to retain the Davonette for the micro-photographic work, the difficulty of which has delayed publication of some of the results which his work has achieved. Illustrations of any paper are indispensable and good photographic results of opaque microscopic objects are not always sufficiently satisfactory for reproduction. This has been responsible for much of the delay. He has now been able to enlist the services of a friend, and he hopes that his photography will be satisfactory for the purpose. At present he is finding difficulty in obtaining plates.

The late Mr. R. M. Laing, who had a research grant for study on Algae, died during the year, and the books and periodicals which had been purchased out of the grant have been deposited in the Society's Library and are available to workers on Algae.

Hutton Grantees.

Mr. L. E. Richdale, who in 1929 was granted £20 for the purpose of studying and ringing birds, reports that he has ringed some 1400 petrels of 5 species at Stewart Island during the last year in addition to other birds ringed on the Otago Peninsula.

Dr. S. N. Slater, who in 1941 was granted £10 for research work on the poisonous constituents of tutu, has forwarded a copy of his completed report, which has been accepted for publication in the *Journal of the Chemical Society*, and with the amount of tutin and picrotoxin still in hand he hopes shortly to complete further work on this subject. He wishes to convey his thanks to the Royal Society for its assistance.

Dr. F. J. Turner, who in 1941 was granted £25 for research on the structural petrology of metamorphic rocks in Central Otago and Fiordland, has reported that the sum of £7 2s has been spent in defraying the cost of 56 oriented sections of schists, peridotites, and metamorphic rocks from Lake Manapouri, and these are lodged in the Geology Department, University of Otago.

A further amount of £8 10s was expended on field work collecting oriented specimens. The balance of his grant will be used in paying the excess cost of a paper published in the *Transactions* on olivine fabrics in peridotites.

Tongariro National Park Board: Dr. Marshall reported on the action which had been taken in regard to the destruction of native plants growing in the grounds of the Chateau. He referred also to the growth of the native vegetation and the spread of heather in the Park. Mr. Aston thanked Dr. Marshall for his report.

Great Barrier Reef Committee: On the motion of Dr. Oliver, his report as representative on the Committee was adopted.

Great Barrier Reef Committee.

Report of Representative.

One meeting of the Committee was held during the year. The Chairman (Professor H. C. Richards) reported that the results obtained from a very full and complete scientific investigation of the boring material from Michaelmas Reef and Heron Island, prepared by himself and Dr. Dorothy Hill, were ready for publication. The chemical analyses of the samples had been carried out by Government Analysts. Publication was authorised. Other reports on Foraminifera had been published or were in hand. The financial statement showed a balance of £1,847 6s 4d, £800 of which was in bonds.

W. R. B. Oliver.

Report of Sub-committee on the T. K. Sidey Summer-time Award.

Following the directions of the 1941 Annual Meeting, the Sub-committee has reconsidered its first report "with a view to ascertaining what amendments are necessary." It has made certain changes in the wording of the amendments as originally proposed by it, but leaving intact the principles involved in its first report. These principles are:—

(1) That consideration shall be given primarily to New Zealand research workers, and

(2) That the award shall not be restricted to completed work, but may be used also to stimulate valuable work still in progress. The Sub-committee considers that the detailed incorporation of these and certain other points in the rules as now proposed would make for greater clearness, and would serve to increase the interest of New Zealand research workers in the Award.

The Sub-committee has endeavoured to frame the amendments in such a way as to avoid any clash with the provisions in the Declaration of Trust. It therefore recommends that the Standing Committee accept the amendments with the revised wording and take any necessary action with respect to them.

Amendment to Rule 1. The wording as it now stands, with the addition of the following: "copies of the notice shall be distributed at intervals of two years to societies, institutions, and persons whose names appear on a list approved by the Council. This notice shall also give information about the subject matter of the research, the qualifications of applicants, and the probable date of the next award."

Amendment to Rule 2. The present Rule 2 to stand and to be numbered 2A. The following to be added and to be numbered 2B, thus:—

"2B. Until such time as the Council shall decide otherwise, the following directions shall apply to the subject matter of the research and the qualifications of the applicants.

"(a) The subject matter of the research must fall under either or both of the following heads: (i) the study of light, visible and invisible, and other solar radiations, in relation to human welfare; (ii) the study of radiations of any kind.

"(b) The award shall be made to some person who has in the opinion of the Council made a valuable contribution to human knowledge by original scientific research in the study aforesaid, or who is engaged in work of this nature which he has advanced to a stage that merits encouragement and is a valuable contribution to knowledge.

"(c) It is emphasised that consideration shall be given primarily to applicants whose researches have been carried out mainly in New Zealand, provided that if the Council considers that no contribution from such applicants is of sufficient merit to justify an award, then the award may be made to some person who was born in New Zealand, or has received the greater part of his or her education in New Zealand, but has not carried out his or her research mainly in New Zealand.

"(d) If the Council considers that there are no candidates of sufficient merit fulfilling the conditions as laid down in clause (c) above, it may, pursuant to clause 4 of the Declaration of Trust make an award under circumstances not complying with those conditions."

A new Rule, to be numbered 7, as follows: "If no award be made on any given occasion, the next award shall be considered after an interval of two years."

The Sub-committee desires to add to its Report the following point which it hopes will be considered and noted in the Minutes of the next Annual Meeting: "That, in the event of any change being contemplated in the future in the Declaration of Trust, consideration be given to the advisability of reducing the minimum value of the Award from £100 to £50."

[See Minutes of Annual Meeting, 1932, Vol. 63, pp. xi–xv; Declaration of Trust and Rules, Vol. 65, pp. 486–490; Minutes of Annual Meeting, 1941, circulated.—Secretary, R.S.N.Z.]

Consideration was given to the proposed amendments to the T. K. Sidey Summer-Time Rules. On the motion of Dr. Allan, seconded by Dr. Oliver, it was resolved that the following amendment to Rule 1, recommended by the Standing Committee, be adopted:—

Add the words "Copies of the Notice shall be distributed to Societies and Institutions the names of which appear on a list approved by the Council."

It was resolved that no amendment be made to Rule 2.

It was resolved to add a new rule as follows:—

Rule 7. If no award be made on any given occasion, a general notice shall immediately be distributed in the same manner as in Rule 1. This notice shall indicate the purposes of the award, the subject matter of the research, the qualifications required of applicants, and the probable date of the next award. The date of such award shall be considered within a period not exceeding two years of such notice.

On the motion of Professor Evans, seconded by Dr. Turner, it was resolved that the Council extend the scope of scientific research

for which the award shall be made so as to include the general study of radiations of every kind.

Science Teaching in Schools: The President read a letter from the Hon. Minister of Education which stated that the Education Department is proposing certain amendments to the School Certificate prescription in order to make it more suitable to the needs of pupils. The prescriptions in science subjects are being widened so as to meet the needs of those who will receive no further teaching of formal science and a syllabus in General Science (including biological sciences) is proposed. Dr. Allan reported that he had obtained a copy of the proposed syllabus and an assurance from the Director of Education that the Society's advice on the various points would be welcome. After some discussion, the proposed syllabus was read and it was then referred to the Standing Committee for early consideration.

Proposed Trust: The President explained how the fund (approximately £530) which it was proposed should be administered by the Royal Society originated.

The donor had given it towards the building and equipment of the Plant Diseases Division of the Plant Research Bureau at Auckland, but as it was not needed for that purpose, it was now proposed that it should be utilised in providing grants-in-aid for botanists and zoologists not on the staff of the Bureau to carry out study at the Bureau or to enable members of the staff to do extra-mural work. On the motion of Dr. Allan, seconded by Mr. Pycroft, it was resolved that the Society accept the Trust.

It was further resolved "That the Council empower the Standing Committee to make grants under the regulations of this Trust Fund."

The President undertook to thank the donor and also Mr Rennie, a solicitor on the Council of the Auckland Institute, who had drawn up the proposed Deed of Trust.

Notices of Motion: Fellowship: On the motion of Dr. Turner, seconded by Dr. Falla, the following motion was carried:—

"That the Council recommend Member Bodies, Fellows, and the Fellowship Selection Committee to take into account whether the research work of the nominee for Fellowship is done in professional or amateur capacity."

Wild Life Control: On the motion of Dr. Falla, seconded by Mr. Pycroft, the following resolution was carried:—

"That the Royal Society considers that improvement in administration of Wild Life matters is still as necessary as when its last recommendations were made to the Government, and views with concern the evidence, submitted by a Member Body, of uninformed policy pursued by the Department of Internal Affairs in matters falling within its jurisdiction."

In support of his resolution, Dr. Falla made a statement regarding the destruction of birds caused by cats on Herekopere Island. A Member Body had approached the Department of Internal Affairs in the matter, but was informed that owing to war conditions and shortage of staff it was impossible to take any action. This attitude was contrasted with that taken by the Department in its conduct of the case of a man who, fearing the extermination of the Southern Robin, had taken it into captivity for breeding purposes.

Mr. Pycroft supported Dr. Falla in his statement of the case. After some discussion, it was decided that Dr. Falla and Dr. Turner should convey the above resolution to the Prime Minister in person.

National Patriotic Fund: A letter requesting gifts of rare books, etc., for an auction sale in aid of the National Patriotic Fund was read. It was decided to contribute a set of "Maori Art" and as complete a set of the *Transactions* as possible.

Hamilton Award: It was resolved that the Hamilton Prize be awarded next year, the Standing Committee to elect the Committee to recommend the award.

Election of Officers: President, Lieutenant-Colonel G. Archey (re-elected); Vice-president, Dr. H. H. Allan (re-elected); Hon. Treasurer, Mr. M. A. Eliott (re-elected); Hon. Editor, Dr. J. Marwick (re-elected); Hon. Librarian: Professor W. P. Evans (re-elected); Co-opted Member: Dr. P. Marshall (re-elected); Managers of Trust Accounts: Messrs. M. A. Eliott and B. C. Aston; Representative Royal New Zealand Institute of Horticulture, Dr. W. R. B. Oliver; Representative Great Barrier Reef Committee: Dr. W. R. B. Oliver; Representatives Observatories' Committee, Professor D. C. H. Florance and Professor P. W. Burbidge.

Election of Committees: Hector Award Committee: Professor Robertson (Convener), Professor Evans, Sir Thomas Easterfield, Mr. B. C. Aston, and Professor A. K. Macbeth (Adelaide).

Library Committee: Professor Evans, Dr. Allan, and Professor Cotton.

Fellowship Selection Committee: Lieutenant-Colonel Archey, Professor Segar, Dr. Allan, Dr. Marwick, and Mr. Aston.

Wild Life Control Committee: Dr. Oliver (Convener), Dr. Allan, Lieutenant-Colonel Archey, Mr. Stead, Dr. Falla, Mr. L. E. Richdale, and Rev. Dr. J. E. Holloway.

Votes of Thanks: On the motion of the President, votes of thanks were accorded to Victoria University College for the use of the Council Room for the meeting and for courtesies extended during the year; also to the press and to Dr. L. Bastings, who represented the Wellington Branch for some months.

On the motion of Mr. Aston, a hearty vote of thanks was accorded to the President, the Vice-president (Dr. Allan), and the Secretary (Miss Wood) for their work during the year.

Next Annual Meeting: The date and place of the next Annual Meeting were left to the Standing Committee to arrange.

REPORTS OF MEMBER BODIES.

AUCKLAND INSTITUTE.

President: Mr W. A. Fairclough.

Director: Lieut.-Col. Gilbert Archey.

Acting Director: Mr A. W. B. Powell

The seventy-third Annual Report of the Auckland Institute and Museum marks the completion of a critical year in a period of great stress for the British Commonwealth of Nations. Under the circumstances, some curtailment and modification of normal Museum activities have been inevitable, nevertheless the Museum continues to carry out its most useful function in the community, particularly in providing educational facilities for the young, and in the handling of technical inquiries.

Staff: The Director, Dr. Gilbert Archey, has been called up by the military authorities, and he now serves as Lieut.-Colonel in the 4th Battalion Auckland Regiment (National Military Reserve).

Mr A. W. B. Powell, Assistant Director, in addition to his regular duties, has been appointed Acting-Director during the term of Dr. Archey's military service.

Mr V. F. Fisher, Ethnologist, is also serving in the 4th Battalion, and Mrs O. M. Turbott has been appointed Acting-Ethnologist during his absence.

Mr R. A. Scobie, Education Officer, is abroad in the New Zealand Expeditionary Force, and Miss Z. O. Lloyd has been appointed in charge of the Education Services during Mr Scobie's absence.

We have recently lost a member of the honorary staff in the death of Mr J. D. Richardson, who rendered valuable service as honorary photographer since 1939. Mr Richardson has bequeathed to us a very extensive collection of photographs, lantern slides and data relating to early Auckland, as well as a fine collection of slides featuring native flora and New Zealand nature subjects generally. These collections will be of definite value both as a research unit and as a source of material for the educational service.

Membership: At the beginning of the year the list comprised 168 life members and 405 annual members. During the year we lost 27 members by death, resignation and deletion, and 26 new members have been elected. The present roll is 572, of whom 165 are life members.

Obituary: During the year we have lost by death many valued members—Hon. Sir James Parr, Ven. Archdeacon MacMurray, Lieut.-Col. J. M. Allen, M.P., Dr Kenneth Mackenzie, Dr Newton Drier, Messrs J. Alexander, J. Catchpole, G. H. Fleming, W. La Roche, J. A. Pond, R. Pudney, J. D. Richardson and G. Ryalls, R.N.Z.A.F. I must refer in particular to the passing of the Hon. Sir James Parr, President in 1913-14, and the Ven. Archdeacon MacMurray, both of whom rendered distinguished services to New Zealand; and to Mr J. A. Pond, who had been a member since the 9th June, 1873. Mr Pond completed 68 years of continuous membership, and both as President and as a member of the Council for 37 years gave valuable and wholehearted service to the Institute and to research.

Congratulations: Congratulations are extended to Dr H. H. Allan on the award of the Hutton Medal, to Dr H. J. Finlay on his being awarded the Hector Medal, to Dr R. A. Falla on his election to Fellowship of the Royal Society of New Zealand, and to Mr E. Earle Vaile on his being awarded the Loder Cup.

A Doctorate of Science has just been conferred on our Director, Lieut.-Colonel Gilbert Archey, and I take this opportunity of inviting you to join with me in extending to him our hearty congratulations.

Council: Six well attended meetings were held during the year.

Finance: Receipts were approximately the same as last year; the slight reduction in members' subscriptions is due to the fact that many of our members are serving overseas. The apparently substantial balance of £1,440 in the General Account must be viewed in relation to the necessity of providing for two "lean" months from the end of the financial year to the receipt of the Museum maintenance contributions.

Museum: The nearer approach of hostilities to our shores has called for greater precautions regarding the safety of our national treasures. A large

cross-section of the collections has been removed to safer quarters in the country and outer suburbs, but the larger exhibits of the Maori Court presented a problem. The large war canoe, 82 feet in length, cannot now be removed from the building, for it was placed in position before the structure was completed around it. However, a considerable measure of protection has been afforded this priceless relic by the erection over it of a framework cover of massive timbers and a layer of sand. The two large pataka, Maori food storehouses, have been dismantled and stowed in a safer part of the building, and the thatch and other inflammable materials removed from the large meeting house "Hotunui."

In spite of the inevitable disorganisation caused by the packing and removal of specimens, the exhibits other than in the Maori Court have not been noticeably depleted, and the Museum services continue to operate satisfactorily, and attendances during the year totalled 161,859.

An exhibit of outstanding interest was received through the generosity of Mr H. R. Jenkins. This is the historic anchor intimately associated with the ill-fated H.M.S. Bounty, for this relic is believed to have been abandoned by Fletcher Christian and his fellow mutineers in 1789, when they used it as a kedge to free the vessel from a coral shoal in the Papaea Arm of Matavia Bay, Tahiti. After generations of Tahitians had made unsuccessful attempts to raise the anchor, it was at last recovered about 1890.

Smith's Bush: During the year strong support was given in respect to the securing of Smith's Bush, near Takapuna, as a nature park. This bush is one of the few remaining examples of the original vegetation of the Auckland area that has survived ancient fires and European settlement. It is characterised by an interesting range of species, great size of the older components, and splendid regeneration of timber trees on its margins. It was gratifying that our local bodies entrusted us to frame the appeal both to the Government and the public. The success in acquiring this valuable area of bush as a reserve is in no small measure due to the efforts of his Worship the Mayor, Mr J. A. C. Allum, his Council and the contributing local bodies. Our thanks are also due to Miss Cranwell for her efforts in this direction, to the Scenery Preservation Committee and the Auckland Botanical Society, also to members of the Council and friends who contributed £100 towards the purchase cost.

In closing my report I would join you in praying for the success of our armed forces and for the speedy return of peace.

THE WELLINGTON BRANCH OF THE ROYAL SOCIETY OF NEW ZEALAND (INC.).

President: Dr M. A. F. Barnett.

Secretary: Mr J. T. Salmon.

The following is the seventy-fourth Annual Report, being the report of the Council for the year ended 30th September, 1941:—

Council: The Council has held ten meetings during the past session.

Membership: The total membership of the Society has increased by ten during the year and now stands at 222. Ten resignations were received and 20 new members were elected.

Meetings: The meetings of the Society and of the Sections have been well attended during the year. The presidential address, which was to have been delivered by Mr F. R. Callaghan, was cancelled owing to the sudden illness of Mr Callaghan. In May, Dr Muriel E. Bell spoke on "Recent Developments in the Knowledge of Nutrition." In June, Dr C. O. Mercer spoke on "The Modern Treatment of Surgical Shock and War Injuries by Transfusion of Blood," and this was followed in July by a symposium and discussion on "The Relationship of Science to Society," in which a number of members took part. On August 27, Dr David Miller, of the Cawthron Institute, gave an address on "Termites" and in September Mr F. T. M. Kissell spoke on "Hydro-electric Development in New Zealand."

Sections: All Sections have continued their activities, and many interesting addresses have been given at their meetings. Two of the Sections now serve supper at the conclusion of each meeting.

Papers for Publication: The following papers were read by title at the General Meetings of the Society and submitted to the editor of the Transactions

for publication:—On May 28, "The Occurrence of *Cryptosparas cranulatus* from Cook Strait," by Mr W. J. Phillipps; "Second Catalogue of Aurora Australis Displays, 1939," by Mr M. Geddes; and "Natural Root Grafts in New Zealand Trees," by Mr A. D. Beddie. On June 25, "The Exoskeleton and Sclerites of *Hemideina megacephala* compared with those of its first instar, *Deinacrida rugosa* and a member of the Dolichopodinae, together with further Notes on the Anatomy and Nervous System of *Hemideina megacephala*," by Mr Ewen Cardale; and "New and Rare Fishes of New Zealand," by Mr W. J. Phillipps. On August 27, "Observations of Jupiter for the Period 1928-1936," by F. M. Bateson, F.R.A.S., communicated by Mr M. Geddes. On September 24, "Supplement to the Collembolan Fauna of New Zealand, the Genus *Ceratrimeria* Borner in New Zealand and a new Genus *Novacerus* to replace *Neocerus* (Pre-occupied)," by Mr J. T. Salmon.

Library: All periodicals subscribed to continue to come forward, although their arrival is somewhat irregular. The following books have been added to the Library during the year:—"The Social Life of Animals," by W. C. Allee; "What Engineers Do," by W. D. Binger; "The Air and Its Mysteries," by C. M. Batley; "Romance of Fire," by A. M. Low; "Everyday Science," by A. W. Haslett; "Crystals," by J. Killiar and "The Stuff We're Made Of," by Karmack and Eggleton.

Observatory: The Observatory is in a satisfactory state of repair, and the five-inch telescope is continuously in use by members of the Astronomical Section.

Lecture Room: During the year the dais was improved by the closing-in of the front of the table. A master switch was installed by the epidiascope to control the room lights, a very much needed improvement.

Cutting of Timber, Maymorn Estate: Following agitation in the press and requests to support movements to have this milling stopped, the Council set up a Special Committee to investigate the question. The report of this Committee was published in the press, and the Council decided to take no further action in the matter.

Acknowledgments: The Council desires to express the thanks of the Society to the honorary auditor, Mr R. E. R. Dymock, who has kindly continued to audit the books of the Society; to the press for publicity and other courtesies; and to the various speakers who have helped to make the Society's meetings successful during the year passed.

NELSON PHILOSOPHICAL SOCIETY.

President: Mr. F. G. Gibbs.

Hon. Secretary and Treasurer: Mr O. B. Pemberton.

The Committee submits the following report of the work of the Nelson Philosophical Society for the year ending 30th September, 1941:—

The statement of Receipts and Expenditure shows a credit balance of £1 4s 11d.

The membership of the Society consists of 28 members, and 15 associate members, making a total of 43.

Meetings of the Society have been held as follows:—

1940.

24th October: Display of Exhibits and short addresses—(1) Dr K. M. Curtis, Tobacco Plants; (2) Dr H. O. Askew, Microchemical Reagents; (3), Miss E. B. Kidson, Colour Tests; (4) Sir Thomas Easterfield, Silica Calculi; (5) Mr T. A. Johnson, Plans of Some Public Buildings; (6) Mr W. C. Davies, Recent Accessions to Cawthron Institute Museum.

1941.

27th May: Public meeting in Marsden Hall, Mr H. A. Fullarton, of Public Works Department, Wellington, "Air Raid Precautions."

17th June: Mr V. J. Hawke, Bacteriologist, Nelson Public Hospital, "The Clinical Examination of Blood."

22nd July: Mr E. F. Lord, of Kirkpatrick and Co., Ltd., "Food Preservation."

19th August: Dr D. Miller, "Termites."

16th September: Mr T. A. Johnston, Presidential Address, "Some Aspects of Highway Beautification."

CANTERBURY BRANCH OF THE ROYAL SOCIETY OF NEW ZEALAND.

President: Mr G. Stokell.

Hon. Secretary: Mr R. S. Duff.

The following is the Annual Report for the year ending 31st October, 1941:—

Obituary: The Society has lost by death Messrs R. M. Laing, M.A., B.Sc., T. Stone and F. F. Scott (who died recently, soon after being elected).

Mr Laing joined the Society in 1882, and continued a member until the time of his death. He was President in 1894, 1910 and 1927, and held the position of secretary from 1889 until 1892. He was elected a Fellow of the Royal Society of New Zealand in 1922.

During his long association with the Canterbury Branch he contributed many papers on New Zealand Botany, specialising in Marine Algae, in which field he had an international reputation. He was co-author with Miss E. Blackwell of "Plants of New Zealand," first published in 1906, editor and part author of "Natural History of Canterbury," 1927, and part author of "The Subantarctic Islands of New Zealand," 1909, the two latter works being produced by the Canterbury Philosophical Institute.

His passing severs a link with the Society's most active period and with many notable scientists who predeceased him.

Membership: The position continues to be unsatisfactory; indeed, with nine ordinary members lost by resignation and three by death, as against seven elected, the net total is 126, five less than that of 1940. One associate member has resigned, as against five elected, making a total of eleven.

Council: Changes in personnel include the resignations of Messrs E. W. Hullett (in March) and E. F. Stead (in September). Mr F. J. T. Grigg was elected in place of Mr Hullett. As in 1940, the eleven normal and one special meetings of the Council have been largely taken up with the slow progress of agreement on a satisfactory merger of the Society's Library with that of Canterbury University College.

The Year's Programme: Addresses were as follows:—March (Presidential Address), Mr G. Stokell, "Wild Life Control" (pamphlet published and edited by New Zealand Forest and Bird Protection Society); "Astronomy," Dr D. B. Macleod; "Moas," Dr R. A. Falla (Records of Canterbury Museum, September, 1941); "Petrol and Substitute Fuels," Mr J. Packer; "War Gases," Mr L. W. Ruddle; "The Preservation of Wild Life in Pre-War Poland," Count K. Wodsicki.

Papers: The following papers were presented for publication in the Transactions:—

June 4: "A Description of the Body Appendages of *Balanus decorus* and a Note on the Sub-genus *Megabalanus*," J. T. Linzey; "The Balanomorph Barnacles of the Kermadec Islands," J. T. Linzey.

July 3: "A Detail of the Pukaki Moraine," R. Speight.

September 3: "The Chromosome Complements of Some New Zealand Plants," I. J. B. Hair; "A New Beetle of the Genus *Nicodema*," E. Fairburn.

October 1: "The Influence of Ultra-short Waves on Plant Germination and yield," A. G. Roth.

November 6: "A Note on the Genus *Neurochorena* and the Addition of a New Species Thereto," A. G. McFarlane.

The following papers were presented, but not for publication in the Transactions:—

April 2: "Changing New Zealand Landscape," M. K. B. Cumberland (published in U.S. Geographical Review, October, 1941).

September 3: "Some Mutations in Wheat, Their Mode of Origin and Their Significance for the Stability of This Genus," O. H. Frankel.

October 1: "Winter Distribution of Three Species of Sub-antarctic Penguins," R. A. Falla.

Library Merger: The decision of Canterbury University College on September 30 to accept the agreement to merge the libraries of the Royal Society and of the College, was followed by a Special General Meeting of the Society on November 5, when a motion that the merger take place, in terms of a slightly modified agreement, was passed unanimously. The main outlines

of the present agreement are that the Society's library is to be housed with the Canterbury College Library. The Society's ownership is not affected, and either party can reverse the agreement by giving one year's notice. The combined collection is to be available to members and associate members of the Society under the usual conditions for borrowing. For members of the Society living outside Christchurch a postal loan service is available, provided that the borrower pays the expenses of postage.

Members have been circularised with details of the agreement, essentially the same as those approved by the Society at its recent meeting in November, and it is to be hoped that the privileges of access to the combined library collections will help to keep old members from resigning and encourage new members to join.

Report of the Treasurer: In the General Account the balance has risen from £5 to £8, but this result has been achieved only by rigid economy. The receipts from subscriptions of ordinary members have fallen by £3, but the sale of copies of the Report on the Sub-antarctic Islands produced £4 2s, a welcome contribution to our funds when we are working on so narrow a margin. Interest from investments has remained stationary at £16.

The Farr Memorial Binding Fund still stands at £6 1s, but arrangements have been made to close this account by binding certain volumes presented to the Society by Dr Farr.

No binding of our own volumes was done in 1940, but this year £20 has been appropriated for this purpose from the accumulated interest in the Savings Bank Account.

The Investment Accounts stand at £466, of which £266 is in the Savings Bank and £200 in Government Stock. The balance in the Savings Bank will be invested otherwise when a suitable opportunity offers.

A new item in the statement of Liabilities and Assets is the books in the Library and the spare volumes of the Sub-Antarctic Islands. These are entered at the sum for which they are valued for insurance purposes. No depreciation has been allowed for, as this is probably offset by the annual accretions of periodicals. With this item included, the assets of the Society appear as £2038.

Report of the Hon. Librarian: Except for the merger negotiations, recorded elsewhere, the year has been uneventful. Some binding has been done, and a survey made of binding arrears. Up to the end of 1940, there were about 750 volumes awaiting binding at an estimated cost of £375. Annual additions are 45 volumes, of which funds allow only 20 to be bound. In addition, there are missing numbers of periodicals to be acquired. Individual donors have included Dr C. C. Farr, Mr C. H. E. Graham, Mr P. G. Bamford, and Dr O. H. Frankel.

Report of the Field Club: The Club's activities have been greatly curtailed owing to the absence of many members on active service. The shortage of petrol caused the chief project to be the making of a survey of the plants of Sugarloaf Bush, and in two interim visits 81 species were noted and recorded in a typewritten list. A visit of inspection was also made to the plant life in the vicinity of the Heathcote Estuary.

At the Annual Meeting regret was expressed at the death of the Club's patron, Lady Kinsey. A suggestion that the Club go into recess during the war was not acted upon, after some serious discussion of the problem.

The following officers were elected:—Patron, Sir R. Heaton Rhodes; President, Mr W. B. Brockie; Secretary, Mr M. Hunter; Committee—Messrs A. G. McFarlane, W. E. Moore, F. Reed, W. Wood.

The balance sheet shows a credit of £9 6s 3d.

Riccarton Bush: The Board of Trustees of Riccarton Bush reports that the maintenance of the bush during the past financial year has been carried out with due regard to available income. The salary of the Board's ranger has been increased, as an additional grant was made by the Christchurch City Council for this purpose. The Board tenders its thanks to those individuals, public bodies and organisations which have contributed to its funds.

The removal of European oaks and their replacement by native trees and shrubs has been continued, and a small revenue has been obtained by the sale of oak firewood. By arrangement with the Christchurch Teachers' Training College, working parties of the College students have been carrying out much

needed and useful work in the removal from some areas of certain troublesome weeds, such as the bittersweet, which in the seedling stage has to be pulled out by hand. The Board's thanks are due to Mr L. W. McCaskill for organising these student parties. Noxious weeds are gradually being eliminated; gorse and elder are now practically exterminated, and blackberry is reduced to a few dwindling patches now under control.

The number of visits to the bush is highly satisfactory, and the number of conducted parties of students from schools and colleges seems to be increasing. During the year a visit of inspection was carried out by the President, officers and members of the Canterbury Branch of the Royal Society, accompanied by the Chairman and members of the Board of Trustees of the Bush.

The Board wishes to tender its appreciation of the efficient work done by its ranger, Mr Leonard Armstrong, who has carried out general maintenance and effected several improvements.

Congratulations: The Society extends its congratulations to Dr R. A. Falla, a Vice-president, on his election to Fellowship of the Royal Society of New Zealand.

OTAGO BRANCH OF THE ROYAL SOCIETY OF NEW ZEALAND.

Annual Report for Session 1941.

President: Dr R. Gardner.

Hon. Secretary: Dr H. D. Skinner.

Membership: The number of full members for 1941 is 173, as compared with 178 for 1940. There were four new members. Three associate and two full members resigned, and there was one death.

Deaths: The deaths are recorded with regret of Mr Frank Mitchell and Mr L. S. Hobbs.

War Services: The following members are on active service overseas:—Dr A. M. Begg, Dr Walden Fitzgerald, Mr Owen Fletcher, Mr R. Kirk, Dr J. R. J. Moore, Mr J. M. Paape.

Attendance: The average attendance at junior lectures was 72, compared with 80 in the previous session. The average attendance of the main branch for its first seven meetings was 44, as compared with 52 and 55 in the two preceding years. This year's average of 44 was helped by an attendance of 84 at the third meeting, which was a joint one with the Field Club. The decline in attendance is due to the war.

Representatives on Museum Management Committee: Messrs George Simpson and J. Scott Thomson were again elected.

Conversazione: Owing to war lighting regulations, it was impossible to hold this, the most popular of all our functions.

Portraits of Past Presidents: Portraits are still lacking of W. Arthur, Dr de Zouche, Dr Belcher, and F. W. Payne. In the coming year it is proposed to mount those we have.

Auditorium Fund: This now stands at £1460. An auditorium is the Museum's most pressing need, and it is certainly one of the most pressing needs of this Society.

Native Bird Protection: Towards the end of the session action was taken by resolutions sent to the Minister of Internal Affairs and to other member bodies urging the more stringent application of regulations at Stewart Island and the taking of steps to exterminate cats on Herekopere Island. In this matter the Society is working in co-operation with the Southland Branch of the Royal Society. The subject of native bird protection is one of the "livest" which comes before the Society, as is evidenced by attendance at meetings when it is discussed.

Agriculture: The most vigorous debate in the session arose out of the symposium on "Future Possibilities of Farming in New Zealand," and it is hoped to arrange a similar symposium for next session. The Agricultural Section is undoubtedly the most vigorous section of the Society.

Reports of Branches: The annual reports of the branches are on file and may be consulted at the Museum.

Ordinary Meetings: These are set out on the syllabus supplied to members and to the secretaries of other member bodies.

Thanks of the Society are due to the speakers during the session, to those who provided supper, and to the University of Otago for permission to use lecture rooms.

Original Papers:

Dr W. N. Benson, F.R.S.: "The Basic Igneous Rocks of Eastern Otago and Their Tectonic Environment."

Dr F. J. Turner: "Structural Petrology of Quartz Veins in East Otago Schists."

Dr F. J. Turner: "Current Views on the Origin of Schistosity."

Sir William Benham, F.R.S.: "Fossil Cetacea of New Zealand. V. *Mauicetus*, new name for *Lophocephalus*."

W. George Howes: "New Lepidoptera."

George Simpson and J. Scott Thomson: "Notes on Some New Zealand Plants, and Descriptions of New Species No. 2."

SOUTHLAND BRANCH OF THE ROYAL SOCIETY OF NEW ZEALAND.

President: Dr C. C. Anderson.

Acting Secretary: Mr A. D. Nisbet.

Membership: The Branch membership stands at 46, of which one is a life member and five are with the armed forces. This is considered satisfactory, but members are urged to do their utmost to secure an increase in our membership. To those in the armed forces—D. C. Berry, F.R.A.S., C. Barwell, A. McDonald, A. Ward, J. H. Sorensen—we extend our best wishes, and express the hope that they will all return safe and well in the very near future.

Lectures: During the year, eight lectures were given, and the thanks of the Branch goes to those who gave of their time in preparing and delivering these lectures. The folowing is a list of the speakers and their subjects:—

May 1: Presidential address, "Geology and Evolution," Dr G. H. Uttley.

May 22, "Maori Settlement in New Zealand," Dr H. D. Skinner.

June 26, "Spiders and Spider Webs," Professor Marples.

July 24: "Whales and Whaling," Mr J. H. Sorensen.

August 22: "Penguins," Mr L. E. Richdale.

September 25: "Divining for Water and Metal," Dr F. J. Turner.

October 23, "Petrol and Natural Gas," Miss C. McHaffie.

November 27: "Botany," Mr G. Simpson.

Attendances: Interest has been maintained throughout the whole session, and attendances at both Council and general meetings has been good.

Financial: The year began with a credit balance in the Working Account of £1 18s 1d; and closed with a credit balance of £4 8s 1d. This amount, along with £11 2s 4d in the Life Members' Account, plus £2 7s 5d in hand, gives the branch a total of £17 17s 10d as assets. Liabilities are nil.

Conclusion: Times are very difficult, and as our work in the community is such a valuable one, all members are asked to do all in their power to maintain the attendances and interests of our meetings, and to extend our activities as much as possible.

It is with pleasure we record the completion of the new Museum building and announce the official opening on the 9th May. The new building is beautiful in appearance, and should prove a great asset to this province. Members may well feel satisfaction in the fact that they have so materially helped in this project.

The Branch President, Dr C. C. Anderson, wishes to thank all members for their support in the past, and to express the hope that the forthcoming season will prove as interesting and profitable a one as that just closed.

PRESIDENTIAL ADDRESS

By Lieutenant-Colonel Gilbert Archey.

My first, and very pleasant task, in addressing you from the chair is to thank you all very sincerely for the high honour you have done me by electing me to the office of President of the Society. I have felt that there were others who had merited the honour more highly, and who would have carried out the duties with greater distinction to the Society. My own hopes to have attended closely to our business and to our development and progress have been frustrated by events, but it is gratifying to be able to record how carefully and ably the Society's affairs have been handled by the Vice-president, the Standing Committee, and by Miss Wood, all of whom I thank sincerely on your behalf as well as for myself.

Two distinguished scientists whose names we were honoured to have on our roll of honorary members have passed away during the year.

Sir Arthur Hill, Director of the Royal Botanic Gardens, Kew, met his death by a riding accident which deprived the world of a great botanical leader at the zenith of his powers and influence. He was known personally to many of us, to those who had the privilege of meeting him during his visit to New Zealand and to those who had the added pleasure of enjoying his hospitality and benefiting by his kind interest and help at Kew. His papers on New Zealand plants have helped us to elucidate many of our own botanical problems, and his own charming personality influenced Empire students to co-operation and created international goodwill. The death of Sir Arthur Hill is mourned as a personal loss by many New Zealanders.

Sir William Bragg, famed British physicist, died in March of this year in London, at the age of 79. Sir William was President of the Royal Society of London in 1911-12, Vice-president from 1920-1925, and President again from 1935-40. He was Director of the Royal Institution of Great Britain; Fullerian Professor of Chemistry in the Royal Institution, and Director of the Davy-Faraday Research Laboratory.

With his son, William Lawrence Bragg, he developed the X-ray spectrometer, which revealed the interior architecture of crystals. For this work father and son shared the 1915 Nobel Prize. A famed, sound popularizer of science, Sir William once flatly told the British Association that man has a soul, declaring: "Science is not setting forth to destroy the soul, but to keep body and soul together."

Both of our late honorary members have served their fellow scientists in double measure: by their distinguished researches they have gained the new knowledge that students always eagerly await; by their examples of unremitting labour and of co-operation and help to their colleagues and students, old and young, they have given real meaning to the fellowship of science.

In this time of national crisis, every group or society of citizens, like every loyal individual, will examine its present activity and its own contribution to national strength and security. Therefore the part that the Royal Society of New Zealand can play in these tremendous times must be a matter of concern to every member.

We know that many of our members are individually carrying out investigations at the request of the Government, but the Society as such has not been asked for its co-operation or advice as it was during the last war. When I observe that this seeming neglect of the Society to-day is the result of the recommendations made twenty-five years ago it should not be inferred that the advice given was bad or that it was not followed. In fact, it was ultimately followed to the very good purpose that within a few years the Department of Scientific and Industrial Research was established. Here is at least one beneficial result of planning during the last war; here is an organisation that, established to benefit a nation at peace, stood ready, at the outbreak of war, to organise scientific enquiry in furthering national preparedness.

As a matter of security it is inappropriate to enlarge on this; but it is not inappropriate to express our gratification that the organisation is there in full activity, and our confidence in the energy and ability with which it is carrying out its important task.

Before enquiring further as to the part the Royal Society can play in the national life to-day, I will refer to two aspects of highly organised direction of scientific investigation. One aspect is definitely an outcome of war conditions; the other may continue, indeed to some extent will prevail, in peace. To-day, national security demands secrecy in science, not only as to the results of research, but even as to the nature and direction of the investigations being made. Yet secrecy is the antithesis of the scientific spirit, whose aim should be to promote knowledge. Secrecy in science, as in any other study, breeds authoritarianism and traditionalism; these, instead of looking to the direct argument of observation and experiment, turn to rhetoric and rationalisation to solve problems and approve action, with resultant stultification of scientific progress. Here science finds its chief quarrel with Nazi Germany, where for years research has been prostituted to create secret machines and secret weapons for Germany's selfish advantage or for the destruction of other peoples. Unless extreme nationalism gives place after the war to a wholesome international attitude, we may fear a continuance of this deplorable condition. Another outcome of organised research, controlled team work, is in many respects as necessary and desirable in peace as in war. Here the individual student surrenders part of the freedom enjoyed by the lone seeker; his progress may resemble a march under discipline, but the words "study" and "discipline" are themselves correlates, if not synonyms, and in team work under an inspiring leader "discipline" and that fine scholastic word "fellowship" plumb a new depth of meaning.

The organisation of scientific research will doubtless be extended and intensified after the war, and wise leadership alone will save officially sponsored organisations from becoming stereotyped.

Leadership in directed research should be more than planning. There is, in all joint research by a senior and junior worker, an important teaching element in their association, and the development of this desirable component of research fellowship in State or foundation institutions would perpetuate in them a real university life. It is equally desirable that research institutions should continue to teach the public, and thereby join with universities and learned societies in promoting knowledge.

Apprehension has been felt for the neglect of pure science by Government research institutes; but this fear has, I think, been allayed by the discovered dependence of applied research on the study of fundamental problems. The publications of the great research departments in Australia and New Zealand bear this out, and I myself had the pleasure last year of presenting the Hector and Hutton Medals to two members of the Department of Scientific and Industrial Research, awards generally recognised to have been made for pure systematic zoological and botanical study.

But why should remarks from this chair bear upon outside research departments; perhaps they were better applied to our own affairs. We have a Fellowship of the Royal Society of New Zealand: it is a recognition of distinction in accomplished research conferred on a worker by his colleagues. Could it not be made something more? It is realised that the Fellows of the Society are scattered throughout the country; but there are at least four in each city. I submit that the Fellows, in accepting the distinction conferred upon them, have also accepted a responsibility to promote study and research, and to assist and encourage others as they themselves have been helped. May I suggest that the Fellows of the Society resident in each city meet together, confer with the Council of the local Member Body, and together promote the fellowship in science by which they are designated.

Returning to co-operative research during the war and the present need for concealing the results of enquiry in the interests of national security, there is a danger of this becoming part of national policy, and of information that should belong to science and to the world being withheld for application to selfish national ends.

A long and exhausting war will reduce our national strength and our resources, and may seem to impose upon us a self-protective policy of guarding or concealing our scientific discoveries. I do not suggest that any scientist, whether an independent student or one holding a government or university appointment would accept such a situation. Freedom to seek, to learn and to discuss are, for scientific enquiry, fundamental necessities which it is the duty of this Society and its branches, as well as of its individual members to safeguard. This is not merely to claim a democratic right; the maintenance of freedom in investigation is part of the first great

responsibility of the scientist, his responsibility to truth; for freedom in enquiry is in itself an assuring criterion of truth, which becomes distorted and unrecognisable in chains.

Scientists to-day are becoming conscious of a new responsibility, one that presents them with a difficult problem. The world is looking for a scapegoat; for someone, or something, to blame for present disasters. It has not been slow to look with suspicion at science, and science has an uneasiness that the world, though mostly wrong, may be partly right.

This world attitude is bringing the scientist to realise that it is not sufficient just to place the results of his investigations in the open fields; he is becoming aware of his responsibility for the best use or application of his discoveries for social betterment. Here he will soon sense his own limited understanding of the social effect of new discoveries; he may discern that, instead of conferring immediate benefits, inventions and discoveries may impose new and dangerous strains on economic and social stability. As he himself becomes aware of what Lord Stamp called the social impact of science, he will perceive the need to promote a greater knowledge of science and of the scientific method among his fellow citizens, who will have need to adjust themselves to inevitable changes.

To apply new discoveries to human betterment is to attempt to control both, whereupon a further difficulty confronts the scientist, who now finds himself passing from the familiar ground of quantitative recording of objective experience to the uncertain and, to him, unscientific field of values. Undismayed, he begins to estimate the possibility of applying scientific methods to the study of society itself, and quickly encounters new obstacles in the unmanageable and intractable nature of the material. Natural science seeks to record observed phenomena and to state the relations between them in simple causative laws. Social science encounters a multiplicity and complexity of actions and reactions between intensively individual human entities, and it is seemingly impossible to reduce them to simple, comprehensive laws.

Nevertheless, social generalisations have emerged and have prevailed among peoples as guides to conduct and action. It should not be beyond the scope of scientific method to enquire how these moral generalisations have found issue in human consciousness, and to endeavour to determine how far they are the outcome of systematic observation and logical reasoning, to what extent they have arisen in some actively wondering mind by what is called intuition, or whether they have entered human consciousness by extra-phenomenal inspiration. Here we perceive a challenge to science to probe the fundamentals of human experience for, as Herbert Dingle has suggested (*Nature*, 20th September, 1941), we have now to consider to what extent science has become, not merely a description of an objective external world, but a formulation of the relations between experiences.

These wider fields of study now before us, and their deeper tillage, serve to emphasise the responsibility of science to cherish truth and to guard research from the too close control that may

ensue from over-organisation and direction. In natural science, this might take the form of arbitrary, though well intentioned, withholding of the results of research in the supposed national interest. In social science, with its new and as yet unproved techniques, and with its need for organised enquiry by teams of workers, there may be even greater danger from control by those who for the time being may hold political power.

Reasons for control can be proffered so plausibly—"the national interest," "social betterment"; but mankind cannot thus hide and shelter from what he has discovered; he must brave the storms as well as enjoy the sunshine of his journey forward. It has more than once been asked if mankind is really fitted by his present standard of education and moral training, or by his mere mental capacity, to enjoy, or even to be entrusted with, the material results of scientific research; and recently a leading churchman, apprehensive of man's moral capacity, sought a ten years' respite from further enquiry.

Facing these questions and asking directly, "Can society absorb new material benefits?" "Has man the capacity to absorb new truth?" we also ask, "Shall truth as well as material benefits be withheld until man can, in the judgment of some not infallible human, assimilate them?"

Whatever may be the answer for material benefits which, too quickly introduced, may strain the social structure, with regard to truth the answer must be "No!" Man must experience, and, if need be, suffer, the truth.

So while, for the moment, national security requires us to accept closely organised direction of research, and even concealment of its results, we shall at this same present time continue to cherish our liberal institutions, and our educational and social ideals, together with our duty to pursue knowledge freely wherever it may be found; but let us at the same time promote true scientific fellowship in such manner that when, by victory, we have secured a just peace, we shall find that we have not only preserved our democratic liberties, but have also maintained and fostered a high responsibility, both to truth and knowledge, and to the ideal of service in applying the fruits of research to the betterment of mankind. The immediate need is not so much to have individual freedom, but to preserve the ideal of freedom, and even more to accept the responsibility of freedom. A true fellowship of science, fellowship between scientists and fellowship between scientists and our fellow citizens will help us all to bear and to share that responsibility.

APPENDIX.

ABSTRACTS OF PAPERS READ BEFORE BRANCHES.

The Modern Treatment of Surgical Shock and War Injuries by Transfusion of Blood.

DR J. O. MERCER.

(Delivered to the Wellington Branch of the Royal Society of New Zealand, 28/6/41.)

Up to 1914 there was no known method of preventing blood clotting, but in that year it was discovered that the addition of sodium citrate to blood would prevent clotting. Blood transfusion then became a practical proposition, and after the last war it began to be used in civil practice. With the outbreak of the present war, it was realised that blood transfusion was useful for more than exsanguinated cases, that it was invaluable in all cases of shock, and many war casualties were cases of shock, very often without any external wound or evidence of loss of blood. In *clinical shock,* blood could be lost into the capillary system particularly of the abdomen, the capillaries dilating and acting like a sponge. The blood therein loses its oxygen and the tissues are asphyxiated, the blood pressure falls and the heart-beat slackens. The blood plasma passes out of the vascular system into the tissues.

In performing blood transfusions for the alleviation of shock, blood plasma or blood serum may be given directly without any reference to blood grouping, but if whole blood is administered the blood groups of the donor and the recipient must be compatible. Transfusion of blood of an incompatible group caused intensive toxic reaction, and even death. This toxic reaction was due to the presence of the free pigment hæmoglobin in the blood. In blood plasma and serum the free pigment had been removed, and so there was no danger of complications.

Whole blood will keep in a refrigerator for 14 days, plasma for six to eight weeks, and serum can be kept at ordinary temperatures for 12 months. Dried plasma will keep indefinitely. It is reconstituted with distilled water.

A normal person has about 11 pints of blood in his body, of which about 9 pints is in active circulation. It is safe to draw off one pint.

In cases of shock the volume of circulating blood was lessened. The performance of a blood transfusion restored the balance.

Auckland Institute.

As all papers are in the process of publication, titles and medium of publication only are given:—

"Inheritance of Vivipary in Phormium," H. H. Allan, D.Sc., M.A., F.L.S., F.R.S.N.Z., and Lucy M. Cranwell, M.A., F.L.S.

"Keys to the Pollen Grains of the N.Z. Flora," Lucy M. Cranwell, M.A., F.L.S.

Both to be published in *Records of the Auckland Institute and Museum,* vol. 2 pt. 6.

"The New Zealand Recent and Fossil Mollusca of the Family Turridæ: With General Notes On Torrid Nomenclature and

Systematics." To be published shortly as *Bulletin No. 2, Auckland Institute and Museum.*

Canterbury Branch.

Changing New Zealand Landscape.

K. B. CUMBERLAND.

In a lecture based on his paper on "Changing New Zealand Landscape," Mr. Kenneth B. Cumberland developed Huxley's thesis of the vastly accelerated rate at which Man in 500 years had altered Nature's biological balance as much as in the previous 5,000,000. In New Zealand, it might be said that the same had been done in the last 100 years; the indigenous vegetation had been largely ousted, and only partially replaced with exotics, with incidentally an appalling waste. Commencing in the late eighteenth century, when it might be assumed New Zealand was 54% forest, Mr. Cumberland developed in detail the successive periods and nature of this cumulative alteration of New Zealand's landscape, and illustrated with slides some disastrous results of destructive exploitation of the land.

Chlorophyll Mutants in Hexaploid Wheat and Their Mode of Origin.

O. H. FRANKEL.

A chlorophyll defect in wheat, "virescent striping," found in an F_5 family from the cross, Tuscan $\times$ White Fife, is due to three independent recessive genes (S_1 S_2 S_3). Both parents to the cross are dominant for all three genes, as in an unrelated variety, Hunters. The possible modes of origin of the mutant were discussed, the literature of polymerous mutants in polyploids reviewed, and further proposed work was indicated.

Winter Distribution of Three Species of Sub-Antarctic Penguins.

R. A. FALLA.

Dr. Falla exhibited specimens of three crested penguins of the genus *Eudyptes,* pointing out that the specific characters by which they could be distinguished were in the pattern of head and neck. Dealing mainly with the Big-Crested Penguin, he described the annual cycle of arrival at a breeding place (Bounty Island) in September, laying in October, young able to swim by February, moulting in March, and leaving the island.

The Big-Crested Penguin's winter destination was regarded as unknown in 1930; but since then, records have been more carefully collected and the menace of waste oil from ships has forced an abnormal number of birds ashore dead, or in an effort to clean themselves. The records show large numbers from Cook Strait north to Gisborne and south to Banks Peninsula. At Otago Peninsula, actually nearer to Bounty Islands, they are rare. The evidence suggests a concentration of the migratory movement in a north-westerly direction for some 500 miles, between March and September.

From the little that is known of the range of Tufted Penguins (from Antipodes and Campbell Islands) a similar movement is indicated.

OBITUARY

Arthur William Hill, 1875-1942.

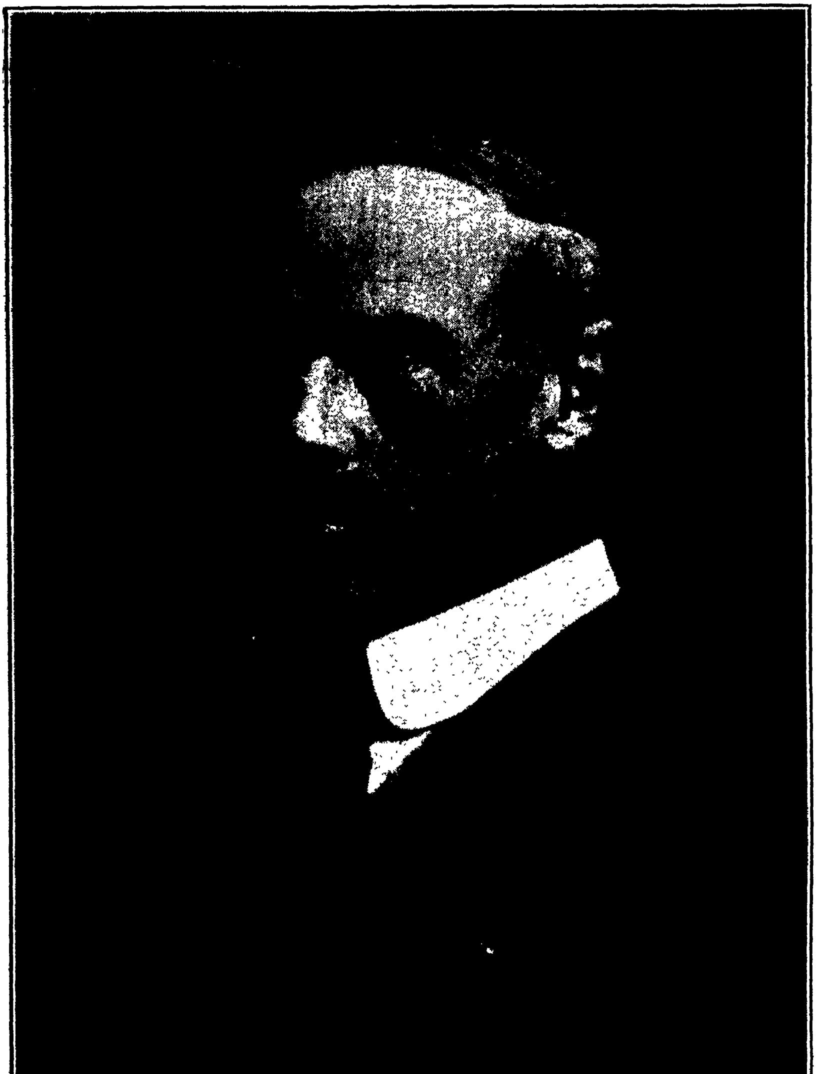
THE long association of Sir Arthur Hill with Kew came abruptly and tragically to an end by an accident when he was taking his customary morning ride. His death, coming at a time when his wide knowledge and administrative abilities were so much needed, will be grievously felt, not alone at Kew and in Great Britain, but throughout the Empire. For Hill was truly the leader of official botany, felt as such in the Dominions as well as in the Homeland, and his sagacious advice on problems submitted to him will be sadly missed.

The only son of Daniel Hill, of Watford, he was born on October 11, 1875, and educated at Marlborough College, where his innate interest in natural history was drawn out by his classical master, the late Edward Meyrick, F.R.S. Hill went on to King's College, Cambridge, of which he came to love every nook and corner. He became a Fellow in 1901, and was very proud of his Honorary Fellowship, awarded in 1932. At Cambridge the lines of his work were greatly influenced by Marshall Ward and later Walter Gardiner, who encouraged that taste for morphology shown in many subsequent papers.

His travels began early, with a visit to Iceland as a member of the Bisiker expedition. In 1903 he was in the high Andes of Peru and Bolivia, an experience that coloured the rest of his botanical career. There was awakened the interest in cushion plants that never left him, and resulted in several important papers. When, later, he reached the summit of Alec's Knob in Westland, he immediately pounced with delight on *Phyllachne* as a worthy subject for study.

In 1907 he joined Sir David Prain's staff at the Royal Botanic Gardens, Kew, as Assistant Director. Besides his routine duties, Hill then commenced his contributions to the various " Kew " floras, especially those of Africa and India, and dealt with several difficult families. In 1922 he succeeded Prain as Director. Thanks to grants from the Empire Marketing Board, he was able to extend the activities of Kew in many ways. Especially, he was able to revive the practice of sending out trained botanists to various countries, and himself visited Australia, New Zealand, Malaya, Rhodesia, East Africa, India, Cyrenaica, and the West Indies. Very fruitful connections resulted from all these visits.

Hill was no mere herbarium man, but took full interest in the gardens themselves and was able to effect many important improvements. His whole-hearted support of economic botany, an outstanding feature of Kew, is revealed in his Presidential Address to Section K of the British Association in 1930, under the title "Present-day Problems in Taxonomic and Economic Botany." " He held the balance," the keeper of the Herbarium, Mr. A. D. Cotton, says, " almost perfectly between the interests of the Gardens and those



The Late ARTHUR WILLIAM HILL, 1875-1942

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of the Herbarium, Museums, and Laboratory, while the versatility of his nature made him capable of taking interest in every aspect of the Gardens' administration."

He rendered fine service also to the Royal Horticultural Society and the John Innes Horticultural Institution, while he was ever ready to help in any movement where botanical knowledge was required, notably any project for the preservation of the natural flora and vegetation. It was in recognition of his high standing and eminent services that Sir Arthur was elected an Honorary Member of the Royal Society of New Zealand in 1928.

No player of games, Hill was never happier than when on horseback, nor will visitors to his home easily forget his delight in his small private old-world garden, where he loved to seek peace and quiet after the labours of the day. Greatly interested in church architecture, he was also a devout churchman, and many can testify to the help given them unobtrusively and gladly by Hill. In the midst of administrative duties he could still fit in some botanical research, and at the time of his death he was engaged on a revision of *Nototriche*. The Gardens were a hobby as well as a duty, and he had in hand a detailed history of them. Hill will be sorely missed when the world returns again from destructive to constructive work.

The visit of Sir Arthur to New Zealand in January, 1928, will remain a vivid memory to those who met him. They will recall the boyishness that kept peeping out from the rather stiff official manner, the glow on his face when he returned from his many rides, the delight with which he squatted in quite unofficial manner to gaze on some plant that attracted his attention, the joy he had in watching from the depths of his armchair Cockayne C. arguing with Cockayne A., for argument's sake. In more serious vein one recalls the shrewd, critical comments thrown into any discussion. One watched, too, scepticism turning into doubt, changing into acceptance, ending in enthusiasm, as the then heterodox views on natural hybridism were expounded and demonstrated.

As a result of his experiences, Hill in 1929 lectured before the Linnean Society on wild hybrids in New Zealand, and in 1935, with Burtt, published a paper on the genera *Gaultheria* and *Pernettya* in New Zealand, Tasmania, and Australia. Other papers of particular interest to New Zealand botanists are his revision of *Lilacopsis*, and of *Caltha* in the southern hemisphere, and his "Antarctica and Problems in Geographical Distribution."

At the end of his visit to New Zealand, Hill presented a "Report on Matters of Botanical Interest in New Zealand." As this pregnant report has not received the full attention it deserves, it is well to repeat in summary form the views expressed. His main points were (1) that a Dominion National Botanic Garden should be established under a director who should be a good systematic botanist with a keen interest in horticulture. This garden, he suggested, should be in one of the main centres, with subordinate gardens in other centres, all under the one control ("One of the main difficulties in considering the question of a Dominion Botanic Garden is that Botanic

Gardens *do not exist* in New Zealand except in title and by Act of Parliament ") ; (2) that there should be a main Dominion Herbarium under the charge of a Keeper of the Botanical Department of the Museum in which it was housed, assisted by an adequate staff; (3) that a Professorship of Botany should be established at one of the centres, and that good botanical posts should be made available, so that there could be "a flow of younger men to carry on the good work which has been done in the past by distinguished New Zealand botanists "; (4) that a liaison officer should be sent to Kew periodically, as has been done by Africa, India, and Australia; (5) that the National and Scenic Reserves, which very greatly impressed him, should be in some way connected with the Director of Botanic Gardens.

Under a somewhat chill and formal exterior, Hill carried a genial and kindly heart. He would with as much zest demonstrate to a raw colonial how to roll a " brolly " as how to marshal his data for a paper. A visitor to Kew, provided he came to work and showed a proper respect for " the hub of the Empire," would receive the fullest help and encouragement. From Banks to Hill, Kew has had its great directors, and Hill is not the least of these. He never lost the love of the classics derived from his Marlborough days, and was apt in quotation from his favourite Latin authors: *Atque in perpetuam, frater, ave atque vale!*

H. H. ALLAN.

TRANSACTIONS

The Body Appendages of *Balanus decorus*.

By J. T. Linzey,

Department of Biology, Canterbury University College.

[*Read before the Canterbury Branch, June 4, 1941; received by the Editor, December 10, 1941; issued separately, June, 1942.*]

Although as early as 1851 Darwin realised the importance of the body appendages in the classification of the sessile barnacles, little work was done along these lines until 1916, when Pilsbry published his monograph. This masterly treatment of the genus *Balanus* and its detailed descriptions of the appendages of the various species, has paved the way to a fuller understanding of this difficult problem. Broch (1922, p. 314), examining the material collected by the Dr. Th. Mortensen Pacific Expedition of 1914–16, stated that he was unable to point out the similarity between the body appendages of *Balanus campbelli* and *Balanus decorus* as the details of the latter species had not been published. Darwin, who first described this latter species in 1854, was acquainted only with the hard parts. So it is desirable that a description of the body appendages should be made.

Description of the body appendages of *Balanus decorus*:

Cirrus I. The anterior ramus is longer than the posterior by about four segments. Some of the basal members are slightly protuberant. The spines, which are long and numerous, are arranged more or less in three whorls, those of the middle whorl being longest while the anterior members of each whorl tending to be longer than the posterior. About 22 segments. The posterior ramus is composed of about eighteen segments, with large protuberances. This ramus, unlike the anterior, is similar to the rami of cirrus II. The pedicel is moderately long and broad and clothed on its posterior edge with dense spines. There are a few shorter and stouter spines on the anterior edge.

Cirrus II. The anterior ramus is longer than the posterior by about four segments, otherwise the two rami are similar. The segments are all very protuberant, this structure bearing upwards of 25 long spines. A row of long spines occupies the anterior half of the distal border of each segment. Postero-distally there is a tuft of about twenty spines of medium length. Between these two sets of spines the distal border is completed with a row of short erect spinules. The pedicel is short and broad, bearing tufts of spines in its anterior and posterior distal angles.

Cirrus III. The anterior ramus is longer than the posterior by about four segments. Both rami are only from one quarter to one third longer than the corresponding rami of cirrus II. The segments of the anterior ramus are somewhat protuberant and three times as

broad as they are long. Anteriorly there are six long pairs of spines. Arranged posteriorly along the distal border is a short row of small spines. Completing the distal border is a row of small erect spinules. The posterior ramus is composed of about fifteen segments which are similar to those of the anterior ramus except that the proximal pair of spines is usually short and downwardly directed as in cirri IV, V, and VI. The pedicel is relatively long and broad and clothed in spines.

Cirrus IV. The anterior and posterior rami are equal in length and composed of about thirty-four segments, each bearing anteriorly three pairs of long spines with a fourth (proximal) pair of short downwardly-directed spines. There is a group of eight small spines on the posterior distal angle. The distal border bears a row of small erect spinules. The pedicel is long and narrower than the third. Its anterior edge is spinose and a small patch of spines occurs on the posterior distal angle.

Cirrus V and Cirrus VI. The rami are nearly equal in length and composed of about forty segments, each bearing anteriorly three pairs of long and a fourth (proximal) pair of short downwardly-directed spines, as in cirrus IV. There are usually only four posterior spines. The distal border bears a row of short erect spinules. Occasionally the segments are somewhat protuberant and sometimes short tufts of spines are apparent between the pairs of spines of the sixth cirrus as occurs in *Balanus tintinnabulum.* The pedicels resemble the fourth except that the posterior distal tuft of spines is usually absent.

Penis. The penis, which is about one and a half times as long as cirrus VI, is distinctly annulated, bearing a few fine hairs.

Labrum. The notch is deep and narrow, the edges straight and bordered with fine hairs which continue right into the notch. The inner lateral surfaces of the labrum are covered with fine hairs.

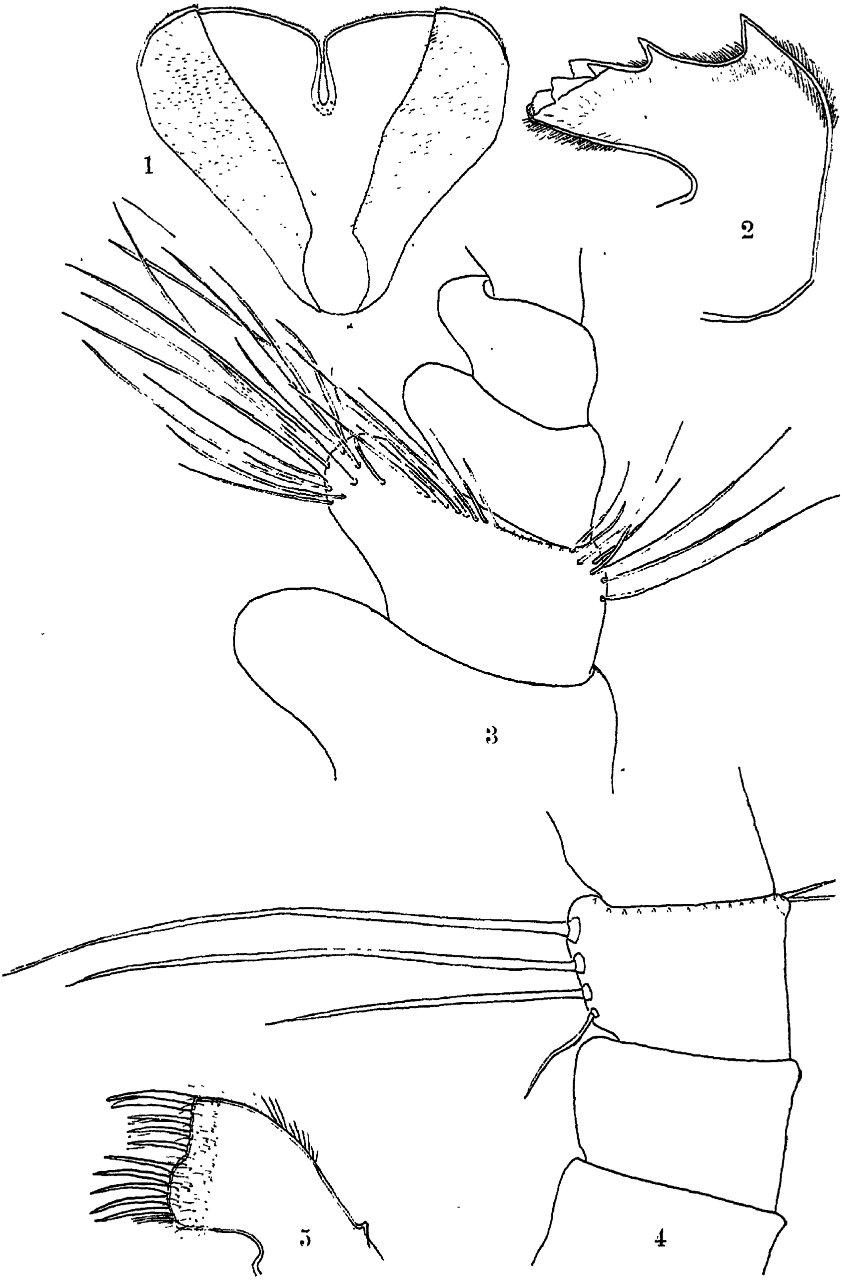
Mandible. There are two large upper teeth, followed by a third, less distinct, and a fourth nearly fused with the basal angle. The lower angle bears a number of minute denticles. A belt of fine hairs lies parallel to the cutting edge.

First Maxilla. This is somewhat variable, but in its simplest form the cutting edge is composed of a long straight " step " followed by a large prominence. The first portion bears one large and three or four smaller pairs of spines, while the prominence bears three to six long single spines. A tuft of finer spines or hairs occurs on the basal angle, while a belt of the same material lies parallel to the cutting edge.

Second Maxilla. Long and sub-triangular in section. The two meet above the labrum and at the point of apposition there is on each maxilla a small depression beset with fine hairs. The two upper surfaces are clothed with long hairs.

Palpus. Relatively large, globose, and densely covered with hairs.

Distribution. Balanus decorus is a common New Zealand barnacle occurring from low water mark to a depth of several fathoms. Two specimens were taken by the New Zealand Government Trawling



Balanus decorus.

FIG. 1. Labrum. × 25.
FIG. 2. Mandible, × 25.
FIG. 3. Cirrus II, Ant. Ramus, No. 13, Seg.. × 75.
FIG. 4. Cirrus VI, Ant. Ramus, No. 32 Seg., × 75.
FIG. 5. 1st Maxilla, × 25.

To face page 2

Expedition of 1907 from a depth of between thirty and forty fathoms. This is essentially a marine animal, but can tolerate slightly brackish water, as evidenced by a fairly large colony in the estuary of the Avon and Heathcote Rivers near Christchurch, where the salinity varies between 28·7 and 33·3 parts per thousand. Chilton (1911, p. 317) observes *Balanus decorus* to occur on the carapace of the crab *Paramithrax longicornis* Thompson and states that it seems to be particularly associated with this animal. The writer has identified five young specimens from the common New Zealand crayfish, *Jasus edwardsii* Hutton, but as yet no larger specimens have been taken from this source. *Balanus decorus* is characteristic of and confined to the New Zealand Region, being common in New Zealand waters and extending west to South Australia (Hutton, 1879, p. 328) to the Chatham Islands in the east and southwards to the Auckland Islands in the Subantarctic group. The writer has identified this species from material from the Kermadec Islands. Withers (1924, p. 26) gives the range in time of this species as Hutchinsonian (Miocene) to the present day in New Zealand. He also reports its presence in the Australian Miocene. This species is often very abundant in more recent New Zealand deposits, and the writer has observed in a pebbly limestone (Pliocene) of Wakarara, Hawke's Bay, thick bands composed almost exclusively of this species and its close ally *Balanus tubulatus* Withers.

Subgenus MEGABALANUS Hoek.

Balani having parities, basis and radii permeated by pores.

A description of the following species, containing an account of the body appendages has already been published:- *Balanus tintinnabulum* (Linnaeus) and *Balanus agricola* Pilsbry by Pilsbry (1916, pp. 56 and 73) and *Balanus campbelli* Fihol by Broch (1922, p. 313). A comparison of *Balanus decorus* with the type *Balanus tintinnabulum* is set out in tabular form below (Table I). Of the short rami of cirrus III, Pilsbry (1916, p. 52) says: "In *B. tintinnabulum* (various varieties) and *B. agricola* the cirri are rather characteristic. The rami of the third pair are exceptionally short, like those of the second pair, the pedicel rather long and the first segment extremely broad. Whether this particularly characterises the other species of the *Megabalanus* I do not know." Since then Broch (1922, p. 313) has reported this feature to occur in *B. campbelli*. He has also pointed out a close relationship between this species and *B. decorus*, but states that a comparison of the body is not yet possible as details of *B. decorus* are missing.

Comparison of *B. decorus*, *B. campbelli* and *B. tintinnabulum*.

The Cirri. In general form the cirri of all three species are similar, but the relative lengths of the rami show a significant variation. Although cirrus III in all cases shows a greater similarity to cirrus II than cirrus IV, here also differences in relative size are apparent. The peni likewise show variation. These differences are summarised below in tabular form (Table II). Unfortunately a specimen of *B. campbelli* was not available, and the lengths given

for this species are only approximate, being based on Broch's description. Differences in structure occur in segments of cirrus VI. In *B. campbelli* the fourth (proximal) pair of anterior spines is longer than in the other two species. There is a variation in the arrangement of the spinules edging the distal borders. In *B. campbelli* the row is arched; in the lower segments, double; or the spinules may be arranged in groups near the bases of the upper spines. In *B. decorus* the row is straight and rarely double; no case was observed where the spinules were crowded together. In *B. tintinnabulum* the row is straight and apparently always single. In this species there is always a tuft of hair between the paired spines of the anterior edge. Although this has been observed in a few specimens of *B. decorus,* it is not reported in the case of *B. campbelli.*

Labrum. The notch is deep in all three species, and the edge, which is fairly straight throughout, is most rounded in *B. campbelli* and straightest in *B. tintinnabulum,* with *B. decorus* intermediate between these forms. In the two latter species the edge bears fine hairs. In *B. campbelli,* Broch (p. 312) reports: " Close by the notch the margin has on each side three low transverse ridges, each with a rudimentary denticle at its top." Pilsbry observes small denticles sometimes to occur in *B. tintinnabulum,* but no trace of this structure was observed in any of the *B. decorus* material examined.

Mandible. The mandibles of *B. decorus* and *B. campbelli* are very similar, differing from *B. tintinnabulum* by the possession of only two strong distinct teeth instead of three, by having a belt of hairs lying parallel to the cutting edge, and by having a denticulate basal angle which seems to be entirely absent in the latter species.

Maxilla. In *B. tintinnabulum* the edge is straight, while in the other two species there is a large basal prominence. This bears large spines which in the case of *B. campbelli* are as large as the first pair. A belt of fine hairs lies parallel to the spine-bearing edge. The chief difference between these two species seems to be only the larger spines on *B. campbelli.*

It is apparent from the above that the cirri of the three species are very similar, with *B. decorus* intermediate between the other two species, but more closely resembling *B. tintinnabulum.* The mouth appendages of *B. decorus* and *B. campbelli* are very similar, the mandible and maxilla showing no great affinity to *B. tintinnabulum.*

Note. Material was collected from many parts of New Zealand, but the chief source of supply was a large colony in the estuary of the Avon and Heathcote Rivers near Christchurch. Material was examined from Lyttelton Harbour; Akaroa Harbour; washed up on wood from Leithfield Beach, North Canterbury; Kaikoura; St. Clair, Dunedin; Barrytown, Westland; Point Elizabeth, Westland; Raglan, Waikato; Auckland Harbour; also some specimens presumed to have come from the Chatham Islands, but their origin was not definite. The largest specimen was 42 mm. basal diameter and 36 mm. high. The average size was about 20 mm. basal diameter. A set of typical appendages were mounted in balsam and placed in the Canterbury Museum.

TABLE I.

COMPARISON OF CIRRI.

	Balanus decorus.	*Balanus tintinnabulum.*
Cirrus I.		
Anterior Ramus.	Segments not protuberant.	Segments not protuberant.
Posterior Ramus	Segments protuberant.	Segments protuberant.
Cirrus II.		
Anterior Ramus and Posterior Ramus	Both rami shorter than corresponding rami in cirrus I. All segments protuberant.	Both rami shorter than corresponding rami in cirrus I. All segments protuberant.
Cirrus III.		
Anterior Ramus and Posterior Ramus	Both rami only slightly longer than corresponding rami of cirrus II. Segments slightly protuberant; bordered distally with a row of small erect spinules.	Both rami about one-third longer than corresponding rami of cirrus II. Segments slightly protuberant; bordered distally with a row of small erect spinules.
Cirrus IV and Cirrus V and Cirrus VI.	Cirri nearly similar composed of a large number of short segments each bearing three long pairs of spines and a smaller pair. A regular row of erect spinules borders each segment distally. There are usually no tufts of small spines on the anterior edge between the spines of the pairs.	Cirri nearly similar composed of a large number of short segments each bearing three pairs of long spines and a smaller pair. A regular row of small erect spinules borders each segment distally. There are tufts of small spines on the anterior edge between the spines of the pairs.

TABLE II.

Ratio of Anterior to Posterior Ramus.	*B. decorus.*	*B. campbelli.*	*B. tintinnabulum.*
Cirrus I	1.3 : 1	2 : 1	Nearly 1 : 1
Cirrus II	1 : 1.2	Nearly 1 : 1	1 : 1.2
Cirrus III	1 : 1.2	Nearly 1 : 1	1 : 1.2
Cirrus IV, Cirrus V, Cirrus VI	1 : 1	1 : 1	1 : 1
Cirrus II/III	1.2 : 1	Less than 1 : 1	1.3 : 1
Penis/Cirrus VI	1.5 : 1	1 : 2	2 : 1

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The Juvenile Plumage of Some Birds and an Interpretation of Its Nature.

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Kerr (1919, p. 74) and Plate (1922, p. 267) have concluded that the feather succession, from natal plumage onwards, consists of the appearance of a series of parts of a whole; as the former puts it, "the down feather and the definitive feathers which succeed it in the series of moults, are all portions of a single greatly elongated and basally growing structure—the first down feather being its tip, and the succeeding feathers being successive portions of it. The moult consists not in the shedding of the whole feather, but merely in the breaking off of its projecting portion." Newton (1893-96, p. 248) refers to the persistently growing rectrices of the males of a Japanese breed of fowl, the moulting of which is said to be artificially prevented. The fact that continuity can be determined between the first and second downs and the juvenal feathers of the Royal Albatross and Penguins, and between old and new feathers in moulting Penguins, sufficiently reinforces the above quotation and the matter hardly calls for further support. There are, however, discussions of the phylogeny of feathers as a whole and of the nature of nestling feathers which make necessary some reconsideration of the growth and the nature of the structures involved. Pycraft (1907, p. 11), writing about the nestling down of Penguins, says, "it has been suggested that these down feathers are really a part of the actual contour feather." Further, he says, "But there can be no doubt that the neossoptiles represent distinct feather generations," and again, "the bases of the rami of the first become welded on to the tips of those of the second (down)." Ewart (1921, p. 633 *et seq.*) discusses the origin and history of feathers and concludes, basing his conclusions largely on a consideration of the juvenile covering of Penguins, that protoptiles, derived from simple filaments, in some cases acquired the chief characteristics of true feathers. He believes that mesoptiles were interpolated or introduced to cope with an ice age, and that later they were in many cases superseded by true feathers.

1. The Nature of the Early Coats.

The Emu.

Ewart (1921, text-figure 11) has figured what he calls "the first three generations" of the Emu's plumage, a diagram presumably based on the material which is photographed on plate vii, figs. 26 and 27 of his paper. These two figures were apparently from small specimens and appear to be magnified about two diameters. Material from four distinct birds, two alive and bred in Wellington Zoological Park, and two preserved ones, one in the Otago Museum, Dunedin,

and one in the Dominion Museum, Wellington, shows no sign of "three generations" up to 10 months of age. Ewart's material was seven months old. The specimens examined in the present case include a sample about six weeks old, one seven months old, one about nine months old and one about ten months old. Through this series can be traced the wearing down and disappearance of the protoptile. In all cases examined, the tip of the succeeding aftershaft broke away from the calamus of the protoptile so that there was not formed a compound hyporachis.

The calamus of the protoptile was found to contain a pith which, in 70% alcohol, gave the appearance of "cones" to the number of four. In spite of Ewart's view (*op. cit.*, p. 628) that the protoptile of the Emu has no calamus, there does not seem any justification for believing that the structure is not a true calamus.

At about ten months of age the young Emu produced a calamus in the feather follicle, the inferior umbilicus being near to closure. Thus, two feather generations were completed at about this age, the second having the character of feathers which would be moulted by dropping from the follicles, not lost by being broken from the tips of the next succeeding generation.

The relation between protoptile and this second generation in the Emu is similar to that between protoptile and mesoptile in Ducks and Swans (see, e.g., those preceding dorsal contour feathers). It is to be concluded that the second generation of the Emu is mesoptile (which Pycraft, 1907, p. 13, regarded as a probability), and is completed at about 10 months of age, while in a Mallard–New Zealand Grey Duck cross the mesoptile of the dorsal contour feather was completed in about 40 days.

Penguins.

The double-down of Penguins was described by Pycraft (1907) and Clark (1906). As was mentioned above, Pycraft considered that the rami of the first down had become "welded" to those of the second. Ewart (*op. cit.*, p. 638) suggested that the mesoptile may have been produced by lengthening of protoptile barbs and by new formations. His text-figure 14 gives a good impression of the relations between the two sections. This figure shows a feature which is found in the White-flippered Penguin (*Eudyptula albosignata*), namely, the absence of barbules from the region representing the junction between first and second downs, or, as they are called, "protoptile" and "mesoptile." Ewart describes this region of junction as not a true protoptile calamus.

In the present study, specimens of the double down of the King Penguin (*Aptenodytes patagonica*) were examined. The numbers of filaments in each section of four examples were, in first and second down respectively, 15 and 15, 26 and 28, 26 and 26, 28 and 28. In the second case there was evidence that the extra two barbs in the second down had broken ends, as they were blunt. Double downs from a White-flippered Penguin (Plate 2, figs. 2a, 2b, 2c) had each a tuft of 10 or 11 filaments attached to a growing second down consisting of a very much larger number of filaments, most of which

were free distally and were pointed, showing no signs of having been broken off. As far as mere arrangement goes, Ewart's text figure 14 falls between the King Penguin and the White-flippered Penguin.

Ewart's text-figures 3 and 4 (Ringed Penguin) and 14 (Adelie Penguin) show no barbules at the junction of first and second down and between second down and definitive feather. A similar condition occurs in the White-flippered Penguin, but in the King Penguin barbules are continuous between the first and second downs.

As indicated by Ewart (*op. cit.*, p. 630), the junction of the first and second down of Penguins is formed by a constricting, short band of epitrichium, the early separated barbs lying side by side within. When this band of epitrichium is cut and removed, the barbs fall apart and form a single tuft diverging from the base of the second down (Plate 2, figs. 1a and 1b). Sometimes barbs remained gummed together and had the appearance of being fused, but were easily separated. Ewart's text-figures 3 and 4, of the Ringed Penguin feather, show a remarkable structure which he interprets as a complex mesoptile aftershaft "connected with the shaft as well as with the aftershaft of the true feather." He does not say to what extent this complexity was present in his material or whether only a single feather was examined. Without an opportunity to review the material on which the figures are based it is not possible to discover to what extent gumming of filaments, if any, was responsible for that arrangement of barbs. Adhesions of a similar odd nature were seen in down attached to teleoptiles of the Royal Albatross (*Diomedea epomorpha*) but the parts were separated easily even four days after being taken from the bird, when drying had already taken place.

The Royal Albatross.

A feature was present in the "calamus" of the second down of the body contour feather which resembled the condition in the Penguin's double down. On a seven months' old bird the junction between second down and teleoptile of a thigh contour feather was marked by a broad band of epitrichium which could be pushed to and fro quite easily over the enclosed structures (Plate 3, fig. 3c). This band was quite tough, more so than that of the Penguin. The barbs enclosed formed another cylinder deeply marked in ridges which connected the barbs of the teleoptile with those of the second down. A small portion of this ridged inner cylinder carried no barbules on the ridges, but more distally, and still enclosed by epitrichium, barbules were present. A similar condition was found in the connection between second down and teleoptile near the base of the bird's neck.

A Museum specimen of the same species, with age given as one month, had double down of coverts and remiges built as above, as well as what may be neossoptiles of plumulae or filoplumulae, and from which the epitrichial bands appeared to be in process of slipping, perhaps due to preening. The junctions between first and second down in some cases showed continuous barbules and, in others,

gaps in the distribution of these appendages. In all these cases examined, the barbs were free inside the epitrichial sheath exactly as was seen in the King Penguin. In several examples, but occurring irregularly, the barbs in the region of the " calamus " formed a wavy bundle which, after soaking in water, was readily dissected into its separate barbs. These latter seemed to be gummed by means of dried lymph or a similar coagulable fluid.

On the neck of this younger bird, the first-second down junction was in some cases formed by a calamus-like section which was somewhat transparent but contained some pith. This part formed an unsplit cylinder of feather material enclosed by an adherent sheath of epitrichium. In specimens of this kind, when splitting of the " calamus " took place, there were two or more groups of barbs, each attached to its own segment of " calamus." The final splitting resulted in more or less continuity between one barb of second down and a barb of first down. Occasionally two or more of one section would be attached to a barb from the other section, showing that splitting of the " calamus " might be irregular.

Contour feathers from the base of the neck and bearing second down had barbules continuously throughout, the difference between teleoptile and second down sections being marked by a sudden change in the form of the barbules (see Plate 4, fig. 4, *Pachyptila turtur*). More distally there was no indication of the region of junction of first and second down, suggesting that this had been formed by a band of eptrichium binding a bundle of separate barbs in a similar manner to that seen in the double down of the King Penguin.

Down from the undercoat of the neck of the one month old Albatross contained examples which resembled mesoptiles in that they had a rachis-like structure, but of an unusual form. The pinnate structure was irregular and the barbs branched dichotomously, forming a feather much unlike a mesoptile as found in the Duck or Swan. The rachis-like structure could have been formed by fusion of barb rudiments during development. They are not regarded as true mesoptiles.

The first down on the head of the Albatross seems to break off as a tuft, the second down forming a velvety surface. On the neck and elsewhere the first down, by splitting of the " calamus," remains as filaments continuous with the second down filaments. These first down barbs are gradually preened away, so that in the one month old bird much of the first coat is lost.

In this double down of the Royal Albatross some feathers possessed the same number of first down barbs as of second, while others had more second than first, suggesting either an increase in the former or a decrease in the latter. The excess second down barbs had pointed ends and were free of the " calamus." The same applies to the relation between teleoptile and second down. Similar arrangements have been noted in Penguins.

A dorsal contour feather of *Pachyptila turtur*, in the fledgling stage, showed an absence of barbules at the first-second down junction and a sharp discontinuity in length of barbule at the second-down-teleoptile junction. The barbs of the aftershaft of the teleoptile

were not continued as second down, and almost all of the barbs on the shaft were continued as second down barbs (Plate 4, fig. 4).

The double down and its relation with the definitive feather in the Albatross show, except in the doubtful case of the underdown from the neck, a complete absence of rachis and hyporachis. The rachis of the teleoptile extends not at all to the second down, and as far as has been observed, the barbs of the aftershaft are not continued as down filaments.

The Black Swan (Chenopis strata).

The nature of the neossoptiles of this species is generally similar to that of the Mallard as described by Ewart (*op. cit.*). Emphasis must be laid on the mixture of neossoptiles, in both Ducks and Swans, consisting of a clear succession of protoptile, mesoptile, teleoptile, with rachis running throughout and a true calamus between the sections, and a double down built on a plan similar to that found on the neck of the Royal Albatross, where was a calamus-like junction of unsplit material with adherent epitrichium, and no rachis in either section of down. The first down, in this type, appeared to fall as a tuft by the breaking away from the proximal side of the calamus of the barbs of the second down. The head bore a double down which was clearly protoptile and mesoptile.

Ewart (*op. cit.*, pp. 613–618), in dealing with the wing-quill mesoptiles of the Mallard, refers to the suppression of mesoptile in *Anseres* and *Galli*, and figures (text figure 5), from the Chinese Goose, the relations between protoptile, mesoptile, and teleoptile. An ulnar remex from the Black Swan showed what may be a vestige of mesoptile, quite absent from other specimens examined, the protoptile being well developed and having a short hyporachis with two barbs. Generally in these remiges, as well as in ventral contour feathers, there was a strap-like and perforated portion running in from the protoptile calamus and terminating freely behind the teleoptile. This may represent the highly modified teleoptile aftershaft as figured by Ewart (see above).

The Woodhen.

Out of nine remex feathers from a chick of a Weka or Woodhen (*Gallirallus australis*) all of which had well-developed protoptiles each with a long rachis, one showed a structure which may be identified as a vestigial mesoptile. The structure resembles that on the remex of the Black Swan, mentioned above, and is to be interpreted according to Ewart's text figure 5. Ewart's view that the mesoptile has become reduced or is gone would seem to be applicable beyond *Anseres*. Reference will be made later to his inclusion of *Galli* in this consideration.

The general juvenile plumage of the Weka, apart from that of the remiges and rectrices, consists of a single down similar to that of the domestic Fowl, with barbs and barbules. There is a connection between the tuft and the teleoptile consisting of an upsplit cylinder covered with epitrichium. This cylinder splits longitudinally as in the Tern and others.

The Pukeko or Swamphen.

Porphyrio melanonotus has neossoptiles similar to those of *Gallirallus.* A feature of this juvenile plumage is that the young down feathers are enclosed in epitrichial sheaths which remain for a long time. A young male, 9 inches high to the crown of the head, still bore sheaths on neossoptiles on the front of the head and on remex protoptiles.

The White-fronted Tern (Sterna striata).

In this bird is a single coat of nestling down consisting of filaments with barbules, based on a more or less incompletely split tube with adherent epitrichium and continuous with the tips of most of the barbs of the teleoptile. The splitting of the connecting section ("calamus") is irregular so that several down barbs may be attached to one teleoptile barb. No rachis was found in the down.

The Domestic Fowl (Gallus gallus).

Here the nestling down resembles that of the Tern in its relations with the teleoptile. On the neck the down breaks away entirely, as a tuft, from the juvenal feather, but generally elsewhere the "calamus" splits longitudinally as in the tern. The condition in the Pheasant and Californian Quail resembles that of the domestic Fowl.

The Domestic Pigeon (Columbia livia).

The nestling down resembles that of the Fowl except in its lack of barbules. A tail quill from a young fantail Pigeon showed the tips of the teleoptile barbs tapering to join the down "calamus." The barbules of this tapering part became rapidly shorter and finally disappeared, leaving a bare termination. The short, tapering portion broke away and was dropped with the liberated tuft of down, so that a relatively uniform distal border was left on the teleoptile. This portion agrees in position with what Ewart (*op. cit.*, pl. x, fig. 38) calls vestigial mesoptile. It is in fact a portion of the teleoptile (Pl. 4, fig. 6).

Passerine Birds.

These, as is well known, offer a final expression of the modification of nestling down. Not only is there a marked reduction of filaments in each tuft, but there is a marked reduction in the extent of down-bearing areas, such nestlings as those of Blackbird, Starling and Chaffinch having only vestiges of down tracts. The English Sparrow is quite naked until the juvenal coat appears, although Dwight (1900) says that it has a natal down of a mouse grey colour.

The natal down of Starlings and Blackbirds is shed as tufts, the barbs of the teleoptile breaking away, one by one, from the unsplit "calamus," which is still encased by epitrichium. Morphologically, the relations are similar to those of the Pigeon and the Fowl.

2. THE USE OF TERMINOLOGY.

The names applied to the various coats and parts of coats of juvenile birds give the impression that homologous structures are dealt with throughout. At the same time, references are made in literature to views which appear to conflict with such an impression. Pycraft has already mentioned the suggestion that the nestling-down feathers of Penguins "are really a part of the actual contour feather,"

and Duerden (1911, p. 5, footnote) says, "It has recently been shown that in many birds the barbs of the new feathers are directly continuous with the barbs of the down feathers, no real break occurring between the two. For this reason some writers consider that the down feathers do not represent a distinct plumage, but are to be looked upon as the modified tip of the true feather (the definitive feather)."

The consideration of the phylogeny of feathers seems to have led to the view expressed by Ewart (*op. cit.*, p. 636), that the phyletic sequence was first the filament, such as is found in many newly hatched birds (e.g., Emu, Penguin, Royal Albatross), next, hair-like barbs (compare with the nestling down of the Pigeon), followed by a "protoptile" of barbs provided with barbules, as in the Penguin. Ewart says (p. 637), "a series of links connect the relatively simple umbelliform protoptiles of Penguins with the highly specialised protoptiles of Ducks and Emus." He believed that the evolution of birds took place in arid conditions followed by a glacial period, and that the latter had set in before wing-quills and other true feathers were evolved. This involved the interpolation of a furlike coat exemplified by the "mesoptiles" of Penguins.

The facts presented above in part 1 suggest that juvenile plumages as a whole have undergone some modifications, to various extents, since the birds arose. At this stage it is not necessary to inquire closely into the origin of neossoptiles, but rather to determine homologies by a comparative study.

The Ducks and Swans present neossoptiles having a resemblance in the fact that there are continuous first and second "down" feathers possessing in each part a rachis which is structurally continuous with that of the definitive feather. The same applies to the down on the remiges and rectrices of the Weka and the Pukeko. The first two feather generations of the Emu have similar relations. There appears to be no reason to doubt that in different birds comparable parts of these structures are homologous and that, when in most complete succession, they are protoptile and mesoptile followed by some sort of teleoptile (cf. Newton, *op. cit.*, p. 243). In this succession the barbs of one section, particularly in the Emu, are independent of the barbs of another, there being a more or less pinnate series of them along the rachis.

In some other birds, however, the situation appears to be very different. Those species dealt with in this paper include examples in which neossoptiles are very much unlike the above. The Penguin presents such a case in one of its most obvious forms. Here, from the early appearance of the second down, as noted in *Eudyptula*, there is continuity of individual barbs from first down to second, and on the removal of the constricting epitrichial sheath the barbs can be separated without further breaking of tissue. Further, in the King Penguin there is a continuous series of barbules along the barb of the double down. There is no rachis or hyporachis in the double down, these being restricted to the teleoptile. The junction between second down and teleoptile of *Eudyptula* and *Megadyptes* appears to undergo delayed splitting, to separate the barbs.

The condition of the Royal Albatross is similar to the above, no rachis or hyporachis except in juvenal feathers, and, except in the head region, a more or less complete separation of barbs within the eptrichial constriction, and generally, on the trunk, a continuity of first and second down barbs with those of the teleoptile. As regards the relation of the three plumages to one another, however, there is almost a complete range of variation between one set of barbs continuous throughout and merely constricted by a loose epitrichial girdle, and that of distinct sets of barbs separated (as well as united) by unsplit, calamus-like junctions. These junctions between first and second downs on the head and neck bear a close likeness to the "calamus" of nestling down of higher birds, such as the Tern, the Fowl, the Pigeon, etc. The condition in these last-named birds is to be interpreted readily by reference to the Albatross and the Penguin.

The substance of the last two paragraphs is very much in agreement with the sense of the quotation of the footnote from Duerden (see above), and we are left with the conception of two main categories of neossoptiles, namely, those having a rachis and pinnate barbs, preceding the teleoptiles, and those having no rachis but being clearly modified portions of teleoptile barbs. The neossoptiles of the Emu are in the first category, those of the Anserines and Rails are a mixture, those of the Albatrosses, chiefly if not entirely, are in the second, and those of the Fowls, Pigeons, Passerines are in the second.

The clear distinction between the neossoptiles of Emu and in part of Anserines on the one hand and of Penguins, Albatrosses, Galli, Pigeons, Passerines, on the other, makes necessary a reconsideration of the use of the terms protoptile and mesoptile.

Newton (*op. cit.*, p. 243) states, "Neossoptiles are characterised by (1) a very short calamus, (2) an insignificant or ill-defined rachis, if there be one at all, (3) the almost universal absence of cilia, (4) long and slender rami, and (5) absence of an aftershaft, except in *Dromaeus.*" Pycraft (1907, p. 11) says that nestling down feathers "present very different grades of perfection, such for example as may be seen in the umbelliform tufts of loose, woolly down of, say, an owl, the semi-plumose type of the *Galli* and *Anseres,* and the strongly pennaceous type of some *Tinami.*" He concludes that "the full sequence is represented (1) by neossoptyles, composed of (A) pre-pennae, divisible into α-protoptyles and β-mesoptyles; (B) pre-plumulae, and (2) teleoptyles or definitive feathers." On p. 12 he says, "This second generation of feathers we may call provisionally 'mesoptyles.'"

It is seen, then, that the terms "protoptyle" and "mesoptyle," used by Pycraft, apply to generations of feathers without any particular reference to their structure. Newton appreciated the varied structure of his neossoptiles without any great emphasis on the succession, if, indeed, he were aware of it. Ewart elaborates the knowledge of structure and succession and considers all neossoptiles to be fundamentally homologous, and uses the terms "protoptile" and "mesoptile" to lead to that conclusion. In the present study, however, it has been shown that the nestling down of Albatrosses and Penguins consists of modified teleoptile barbs, and that the structure

of the neossoptiles of *Galli, Passeres,* and more or less of the nestling down of *Ralli* and *Anseres* may be similarly interpreted. It is also clear that this kind of nestling down is fundamentally different from the first plumage of the Emu and from that part of the juvenile plumage of the Duck and the Swan which possesses a rachis.

To clarify the issue it is here proposed to restrict the term *protoptile* to apply to the primitively first, rachial neossoptile, and to restrict the term *mesoptile* to apply to the primitively second, rachial neossoptile. These restrictions make necessary new terms to cover the different modifications of precocious teleoptile barbs. The term *haploptile* is here proposed to designate the single non-rachial neossoptile formed by precocious elongation and appearance of the barbs of teleoptiles. The term *diploptile* is proposed to designate the double, non-rachial neossoptile formed by precocious elongation and appearance of the barbs of teleoptiles. The term *pseudo-protoptile* is proposed to designate that part of the double, non-rachial neossoptile which appears first in the succession. The term *pseudo-mesoptile* is proposed to designate that part of the double, non-rachial neossoptile which appears second in the succession.

For the purpose of exactitude, the terms protoptile and mesoptile, as used above, are applied to the rachial neossoptiles of *Anseres*, in particular, *Chenopis strata.* The term haploptile is applied to the non-rachial neossoptile of *Galli,* in particular, *Gallus gallus.* The term diploptile is applied to the non-rachial neossoptile of *Spheniscidae,* in particular, *Eudyptula albosignata.*

The foregoing application of terms makes necessary a further classification, viz.: that of the use of the word *Calamus.* This word is particularly applied to the proximal, hollow, transparent, unsplit part of the adult feather, which is normally held in the follicle. It is made up of median and lateral material, i.e., material which is continuous directly with rachis and barbs and hyporachis (if present) of the preceding feather. Obviously, then, the term calamus cannot apply to the proximal part of a haploptile or to a part of a diploptile since there is no median material in it or in the preceding neossoptile; it consists of modified parts of teleoptile barbs. The term *pseudo-calamus* is here proposed to apply to the proximal part of a haploptile, or of a pseudo-protoptile, or of a pseudo-mesoptile, which, by its relations, contains only lateral material, continuous with the barbs of the neossoptile preceding it and with the barbs of the feather succeeding it. The presence or absence of cones is no criterion of the nature of a true or false calamus.

It will be noted that these neossoptiles derived by modification of teleoptile parts vary in constitution, some containing material continuous with barbs of shaft and aftershaft, as in the Penguin, others consisting only of barbs derived from the shaft, as in Pigeons and higher birds, and in Albatrosses.

3. Some Phyletic Considerations.

The differences of origin and structure of protoptile and mesoptile on the one hand and pseudo-protoptile and pseudo-mesoptile on the other make necessary a review of Ewart's conclusions that

" the protoptiles of Penguins represent a second stage in the evolution of true feathers," and that " a series of links connect the relatively simple umbelliform protoptiles of Penguins with the highly specialised protoptiles of Ducks and Emus." If these conclusions are well based it should be possible to obtain some kind of comparative evidence of the building up of mesoptile and protoptile with rachis and barbs from structures consisting only of barbs and barbules or of barbs only. The material presented in the foregoing suggests that, concerning pseudo-protoptile and pseudo-mesoptile, there is a solid basis of fact to support the view that the barbule-less condition of Pigeons and Passerines represents a modification of the condition like that of Fowl, Quail, Terns, where barbules are present, these latter having many features in common with the neossoptiles on the head of the Albatross, where there is a well-established, unsplit pseudo-calamus. A comparison of this down with the rest of the down of the young Albatross establishes an essential similarity of structure of the pseudo-protoptiles and of the pseudo-mesoptiles of all those birds under consideration. In the present study of the cygnet of the Black Swan or the duckling of a cross between Mallard and Grey Duck (*Anas superciliosa*), nothing has been seen which shows a transition from pseudo-protoptile or pseudo-mesoptile to protoptile or mesoptile. It has been noted by Ewart and confirmed in the present work that in *Anseres* the mesoptile is found vestigial in or absent from certain neossoptiles, and a similar condition has been noted in *Gallirallus*. The conclusion is, then, that there is to be seen a tendency towards the disappearance of true neossoptiles. The alleged suppression of mesoptile in the *Galli*, referred to by Ewart (see above), must be re-examined in the present light, if suppression in fact takes place, and regarded as a reduction of a part or a whole of a pseudo-mesoptile. It can only be analogous to the suppression of a mesoptile in the *Anseres*. The tail quill of the young Pigeon, described earlier, with the peculiar terminations to the distal barbs of the teleoptile, may be an example of degenerating pseudo-mesoptile or may be a specialisation which has no reference to such a structure.

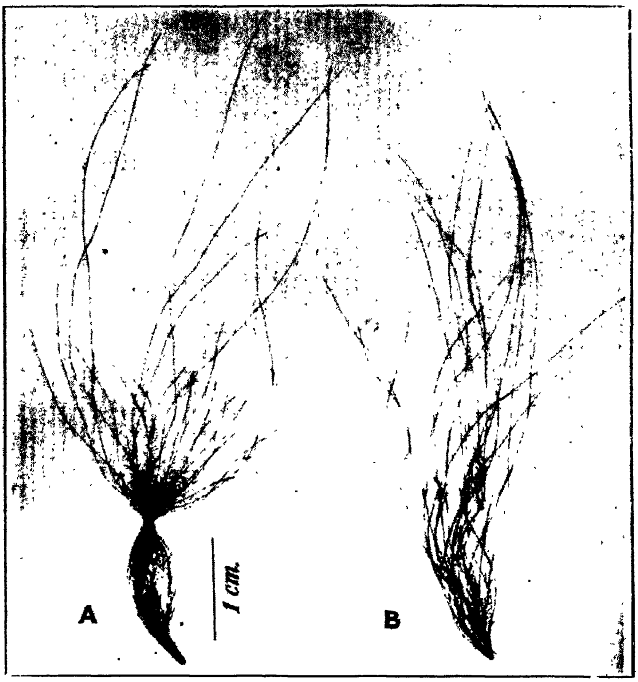
The question of the possible suppression of pseudo-protoptile or pseudo-mesoptile immediately brings up the further question of the relation of the single down of Passerines, Fowls, Pigeons, Rails and others to the double down of Penguins and Albatrosses. Nothing emerges from the literature on the subject which justifies a conclusion that the single down is derived by a suppression of one or other of the parts of double down. The structure of the nestling down of, and its relation to, the tail quill of the Pigeon appears slender evidence on which to build a precedent double down.

(See table on next page.)

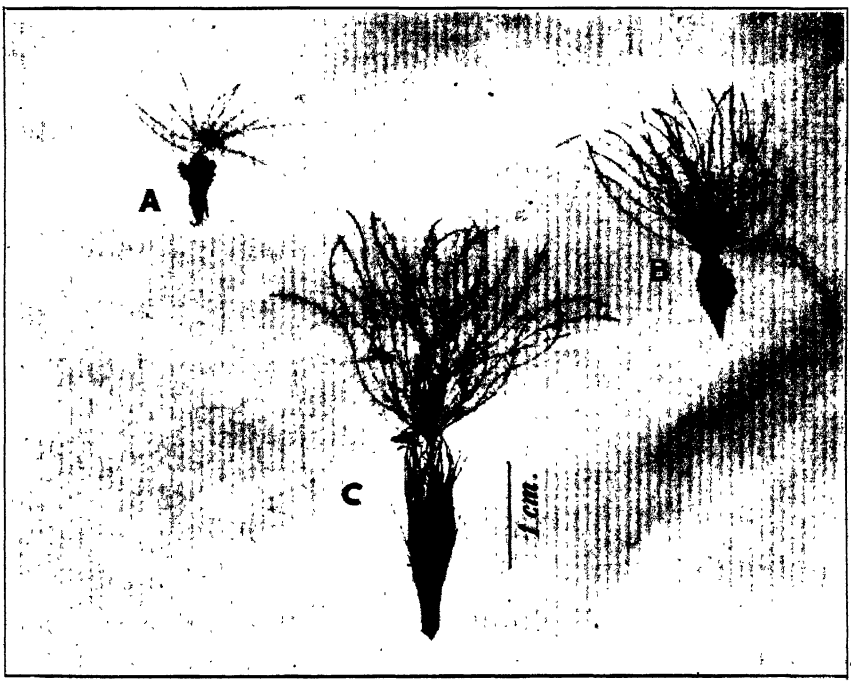
It is advisable to suspend judgment on the question of the phyletic relation of these two kinds of down if we reject the view that the Pigeon has a vestige of a pseudo-mesoptile, since there appears to hand no information that those birds possessing haploptiles do show traces of unequivocal pseudo-mesoptiles. If those birds bearing diploptiles and haploptiles have lost protoptile and mesoptile and have replaced them by modification of the teleoptile, the question arises as to whether the single down or the double down appeared first.

TABLE SHOWING DISTRIBUTION OF NEOSSOPTILES IN BIRDS DEALT WITH IN THIS PAPER.

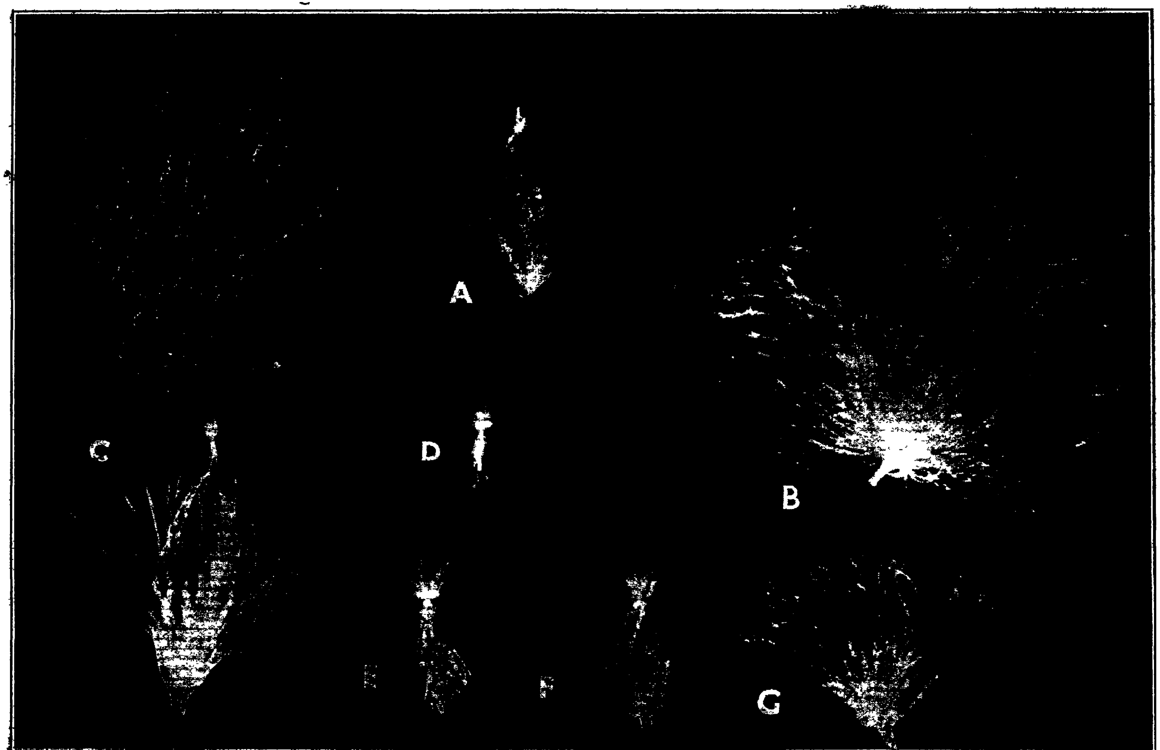
Group.	Genus.	Protoptile–mesoptile succession only.	Protoptile–mesoptile succession mixed with Diploptile.	Haploptile with remnants of Protoptile-mesoptile succession.	Diploptile.	Haploptile.	No Neossoptile.
Ratitae	Dromaeus	+	—	—	—	—	—
	Struthio	+	—	—	—	—	—
Anseres	Anas	—	+	—	—	—	—
	Chenopis	—	+	—	—	—	—
Rallidae	Gallirallus	—	—	+	—	—	—
	Porphyrio	—	—	+	—	—	—
Spheniscidae	Eudyptula	—	—	—	+	—	—
	Aptenodytes	—	—	—	+	—	—
Procellariidae	Diomedea	—	—	—	+	—	—
	Pachyptila	—	—	—	+	—	—
Galli	Gallus	—	—	—	—	+	—
	Phasianus	—	—	—	—	+	—
	Callipepla	—	—	—	—	+	—
Columbidae	Columba	—	—	—	—	+	—
Passeres	Sturnus	—	—	—	—	+	—
	Turdus	—	—	—	—	+	—
	Fringilla	—	—	—	—	+	—
	Passer	—	—	—	—	—	+



1. *Aptenodytes patagonica* (King Penguin). (a) Double down showing part of pseudo-protoptile. The epitrichial band is some distance proximal to the place of breaking. (b) Double down with epitrichial band removed showing independent and continuous barbs. The barbules are shown to be continuous.

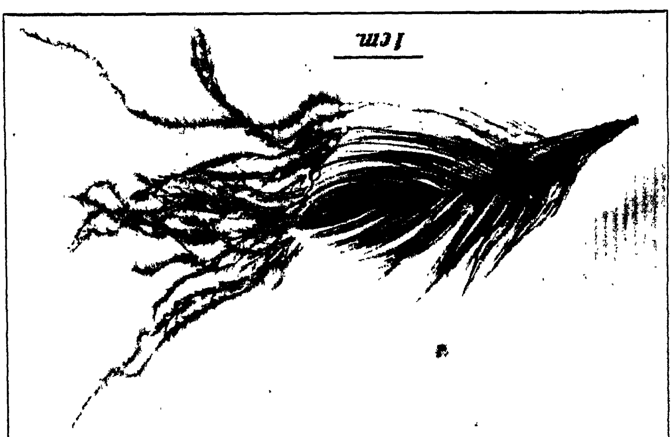


2. *Eudyptula albosignata* (White-flippered Penguin). (a) Pseudo-protoptile continuous with th

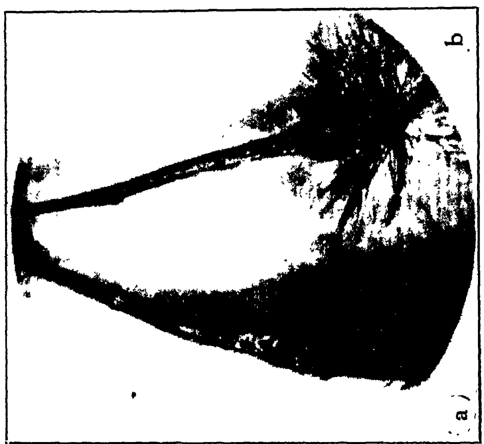


3. *Diomedea epomorpha* (Royal Albatross).

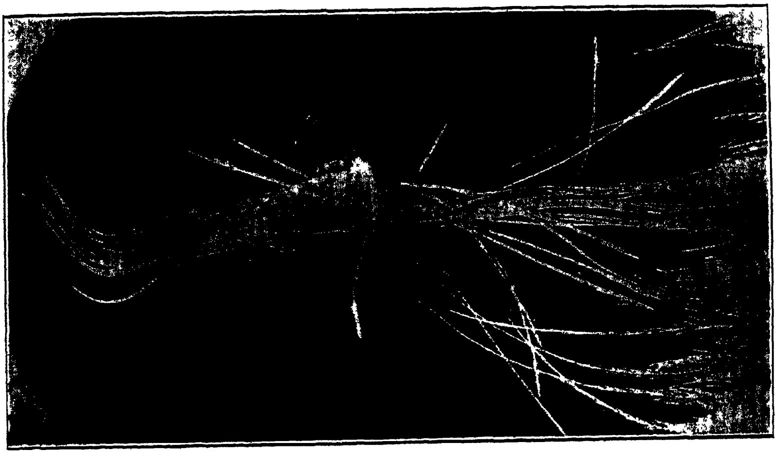
(a) 1 month old. Dorsal double down with pseudo-calamus. (b) 1 month old. Dorsal double down with open connexion between pseudo-protoptile and pseudo-mesoptile. The junctions show no barbules. (c) 7 months old. Thigh contour bearing pseudo-mesoptile. The pseudo-calamus consists of a loose epitrichial sheath and an almost completely split cylinder of feather substance. (d-g) 1 month old. Double downs from band showing slipping off of epitrichial sheath and opening out of split cylinder connecting [redacted]



4. *Pachyptila turtur* (Fairy Prion).
Dorsal contour, with open double down, showing relations between pseudo-protoptile, pseudo-mesoptile and teleoptile.



5. *Porphyrio melanonotus* (Pukeko).
(a) Remex from young male, 9" high. Protoptile bearing epitrichial sheath.
(b) Dorsal haploptile bearing sheath.



6. *Fantail Pigeon.*
Rectrix showing breaking off of tips of barbs and their falling away attached to pseudo-calamus of haploptile.

The palaeontology of the groups containing the species under consideration presents an interesting picture. Lambrecht (1933) leads to the conclusion that the Penguins had attained their specialisation by Miocene times. *Gigantornis*, placed in the *Procellariiformes*, is given as occurring possibly in the Eocene. *Palaeotringa* and other *Telmatoformes* extend back to the Eocene. *Palaeophasianus*, among the *Galli*, is recorded from the Eocene, while other pheasants extend back to the Miocene. The *Ralliformes* are given as extending back to the Eocene, as are the Anserine and Passerine birds. Thus, all those groups of birds under examination, which at present bear haploptiles and diploptiles, are reported from the early Tertiary, so that it is evident that the origin of these forms of neossoptiles must be sought in earlier times, perhaps in the Cretaceous.

It is possible that a haploptile could become a diploptile, similar to that of a Penguin, by the persistence of an epitrichial band situated about halfway along the length. Such a constriction has been observed, not on a haploptile, but on the protoptile of an ulnar remex of a young Black Swan. It is not yet possible to be certain whether it was in its original position or had been caused to slide distally from the region of the calamus by preening. That the latter may be the case is suggested by the fact that the constricting bands of the diploptiles of remiges of the young Royal Albatross were in various positions, from the pseudo-calamus distally, until they had in some cases been lost and the double down had the form of an unconstricted tuft (pl. 3, figs. 3d-g). By retention of the band and a delay in the separation of the constricted barbs a pseudo-calamus similar to that of a contour diploptile could be produced.

The contention of Ewart (*op. cit.*, p. 631), that the development of the nestling feather of the *Galli* in a filament is in favour of its being protoptile, can now be regarded as somewhat beside the point. The appearance of an epitrichial sheath on early neossoptiles of different kinds, as in the Pukeko (pl. 4, figs. 5a and b), is to be regarded more as a fact of development than as one of phyletic significance. Feathers are ensheathed during development, teleoptiles included, and emerge sooner or later from the covering either by extension of barbs or by disintegration of sheath. It is to be remarked that so many of those birds whose neossoptiles develop from filaments are precocious to a greater or less extent, or, on account of exposure, benefit by a rapidly appearing covering.

It is possible to regard the double-down as an adaptation bound up with a long nestling life in rather difficult conditions. Penguins and Albatrosses are known to undergo long periods of parental care chiefly in the open, although the young of *Eudyptula albosignata*, living in holes on the shore of Banks Peninsula, New Zealand, left the nest, fully fledged, at the end of about two months from hatching. *Eudyptula* is stated by Pycraft (1898, p. 981) to appear "to represent the least specialised form of the whole group (Impennes), and probably lies nearest the ancestral stock." It is conceivable that the thick nestling down of the more southerly-living Penguins is a further development of a juvenile coat similar to that of *Eudyptula*. In this genus the first down does not completely cover the skin, a clear-

feather pattern being visible, but when the second down emerges the skin is no longer visible, partly, no doubt, because each feather possesses more barbs than did the pseudo-protoptile and partly because the individual barbs are ultimately longer. This more effective covering by the second down occurs in spite of the rapid increase in the surface area of the body.

The Aftershaft.

The wide distribution through the birds of an aftershaft, either with or without a hyporachis, would lead to the conclusion that it is an ancient structure. Its occurrence in the neossoptiles of *Ratitae*, *Anseres*, *Tinamidae*, *Rallidae*, indicates its existence in juvenile birds since the earliest times. The absence of an aftershaft or a hyporachis from some Ratites may be regarded as due to loss.

It has long been known that the adult coat of *Apteryx* has no aftershaft, but contrary to earlier statements (see, for instance, Pycraft, 1901, p. 163, p. XLV, fig. 61) a remnant of an aftershaft, consisting of about ten barbs carrying barbules similar to those elsewhere on the feather, has been found on feathers of juveniles of *Apteryx oweni*, *A. mantelli* and *A. haasti*. There is no hyporachis, the barbs being rather uniformly distributed round the lower edge of the superior umbilicus. Such an arrangement is absent from adult feathers. The barbs of the aftershaft were observed on one skin to be parallel to the skin, providing a felt-like layer beneath the rest of the plumage.

The nature of the juvenile feathers of *Apteryx* is apparently still in doubt, particularly since there has been found no trace of connection between them and the young adult feathers (Pycraft, 1901, p. 163). According to Pycraft's account of a downy nestling of *A. haasti*, the prepennae fall away before the pennae have differentiated to any extent. Evidently, then, the early feather succession in these birds has undergone considerable specialisation, not only in the character of the adult feathers, but in the nature of the neossoptiles, by reduction of the aftershaft and the discontinuous production of the early feathers.

Conclusions.

After consideration of the foregoing facts it may be concluded that:—

1. In the history of Birds, neossoptile plumage has undergone much change.

2. In the coat of some of the *Ratitae*, and in some parts of the coat of *Anseriformes* and *Rallidae*, the definitive feather of the young adult is preceded by true protoptile and mesoptile or by protoptile and vestigial mesoptile, or by true protoptile only. Where the mesoptile is absent in the *Neognathae*, it is to be regarded as lost.

3. Protoptile, mesoptile and teleoptile form a series of structures produced in the same follicle. Each has a median rachis bearing lateral barbs. The rachis of one is morphologically continuous with that of another; the barbs of one are in the same series as those of the other but are separated from them by the calamus.

4. In many birds the definitive feather of the young adult is not preceded by a protoptile or a mesoptile but by early elongations, variously elaborated, of only the barbs of the definitive feather. The number of barbs thus extended may become so few as finally to produce no nestling down, as in the House Sparrow, *Passer domesticus.*

5. The growth of nestling down at first in a sheath of epitrichium, which disintegrates and leaves the barbs free, is no criterion by which to define a protoptile.

6. The appearance of protoptile, mesoptile and definitive feather (teleoptile), in that sequence, is to be considered as historically precedent to the appearance of nestling down formed as modified extensions of the barbs of the definitive feather, and the nestling downs of Penguins and Pigeons are therefore not to be regarded as representing stages of phyletic significance in the history of feathers.

7. The double down of Penguins and Albatrosses, and similar structures in other birds, and the single down of many birds are not homologous with protoptile and mesoptile of Ducks and Swans and should be given other designations. The terms suggested are as follows: single down to be called *haploptile,* double down to be called *diploptile*, the parts of the *diploptile* to be called *pseudo-protoptile* and *pseudo-mesoptile.*

8. The term " calamus " can be applied only to that part lying between protoptile and mesoptile, between mesoptile and teleoptile and below the teleoptile. The part lying between haploptile and teleoptile, between pseudo-protoptile and pseudo-mesoptile and between pseudo-mesoptile and teleoptile, is *pseudo-calamus.*

9. Those birds which lack protoptile and mesoptile may be regarded as having lost them. Haploptile and diploptile functionally replace those structures.

10. No satisfactory evidence comes forward to show clearly the relation between the haploptile and the parts of a diploptile.

SUMMARY.

The general structure of the juvenile plumage of a number of birds is examined. Two main categories are found, namely, a succession consisting of protoptile, mesoptile, and teleoptile or a modification of it, such as reduction or loss of mesoptile, and an absence of protoptile and mesoptile with usually a functional replacement by precocious elongation of barbs of the teleoptile. In some birds the elongated teleoptile barbs form a single nestling-down or haploptile, in other birds those barbs form a double nestling down or diploptile, in which latter case the first down is designated pseudo-protoptile and the second down is called pseudo-mesoptile.

It is considered that the protoptile, mesoptile, teleoptile succession is primitive.

The presence of an epitrichial covering on a newly hatched nestling-down feather is no criterion of the nature of that feather; a protoptile or a haploptile or a pseudo-protoptile may possess such a sheath. A reduced aftershaft of barbules has been found on feathers of juvenile *Apteryx* spp.

Acknowledgments.

Indebtedness is acknowledged to Dr. R. A. Falla, Director of the Canterbury Museum, who gave free access to and use of the collection of bird material in his care, also to Mr. E. F. Stead, of Christchurch, Professor B. J. Marples and Mr. L. E. Richdale, of Dunedin, and to the Curators of the Zoological Parks of Auckland and Wellington, all of whom provided valuable material.

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Notes on Some New Zealand Plants and Descriptions of New Species (No. 2).

By G. SIMPSON and J. SCOTT THOMSON.

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RANUNCULACEAE.

Ranunculus lobulatus (T. Kirk) Ckn.

Achenes numerous, crowded in a broadly conical dark green head to 1 cm. diam. or slightly more, half obovate in outline, compressed, 3 mm. long including the style, keeled at the back, extended into a straight or oblique subulate beak as long as the achene. Our specimens in the Herbarium, Plant Research Bureau, Wellington, are from plants in cultivation collected on Mount Fyffe, Marlborough, at 720 m. altitude.

Ranunculus novae-zealandiae Petrie.

Petrie described a " glabrous fleshy glaucous plant " with the leaf blades " ternately divided " and " ripe achenes not seen."

On the Rock and Pillar Range—the type habitat—and on the Garvie Mountains, the leaves are invariably dark green with the veins sunken on both surfaces; petioles and scapes purplish, spotted with pale yellow-green, leaf blades 3–5 foliate, or 7 foliate on larger plants; lower segments sessile, the following pair in larger leaves petiolate, the upper ones sessile and the terminal one again more or less distant. Achenes in a rounded head ± 6 mm. diam., turgid, half-obovate in outline, rather more than 1 mm. diam., obscurely keeled at the back, with a short, stout, straight or upturned, subulate beak.

—— var. **repens** nov.

Herba repens, rhizomatis crassis, albis, mollibus, instructa; alioqui ut in typo.

Almost exactly as the type but spreading widely by stout, soft, white underground stems, which occasionally arch above the ground.

Habitat: Debris at Blue Lake, Garvie Mts., 1230 m. altitude.

Type specimens in the Herbarium, Plant Research Bureau, Wellington.

The 3 foliate leaves of small or reduced plants of the species are curiously unlike those of more vigorous growths, and individual plants, differing only in the development of their leaves, might well be mistaken for distinct varieties.

Poppelwell (1915, p. 128) recognised 2 forms on the Garvie Mountains, one with 5 petaled flowers and one 8–10 petaled. The 5 petaled flowers appear to be those of var. *repens*, and 8–10 petaled flowers those of the usual form of the species on this range.

Ranunculus sericophyllus Hook. f.

Cheeseman (1925, p. 444) inadvertently, since it appeared correctly in an earlier work (1914, 1, p. 6), described the achenes as "forming a rounded head 1½ in. in diam." The rounded heads are ± 1 cm. diam., the achenes 2 mm. long, ovoid, glabrous, turgid, keeled at the back, with a stout, straight, subulate beak as long as the achene and in line with the keel. In the Floras of Kirk and Cheeseman it is stated that Petrie's specimens from the mountains at the head of the Matukituki River, near Mount Aspiring, are glabrate or almost glabrous, but his specimens are epharmones with long attenuated leaves with scattered hairs, and their young leaves have the villous character. Cheeseman's plate (*loc. cit.*) illustrates very well the partly folded character of the leaves and their narrow, subacute, and more or less erect segments, but it fails to show the villous character, and the hairs are drawn short and stiff, hirsute.

—— var. **simpsonii** comb. nov. = *R. simpsonii* Ckn. et Allan in *Trans. N.Z. Inst.*, vol. 57 (1927), p. 58.

The glabrous upper surfaces of the leaves, and their fewer and broader segments are the only characters separating the variety from the type. Mr W. B. Brockie has sent specimens from Lake Man, in the mountains above Amuri Pass, near Hanmer, and specimens in the Dominion Museum Herbarium, Wellington, collected at the Freeman River by J. Crosby Smith, belong here.

× **Ranunculus baughani** = *R. baughani* Petrie.

It was suggested to Dr. Cockayne by the authors that this might be *R. sericophyllus* × *simpsonii*, and it was included by Cockayne and Allan (1934, p. 22) under that heading, but we had not found the species together, nor do we know yet where they both occur. The specimen in Petrie's Herbarium, collected above McKinnon Pass by Miss Baughan, has but a single leaf and a 2 flowered scape and with it is a typical leaf of *R. sericophyllus* which was no doubt used in comparison. *R. buchanani* and *R. sericophyllus* var. *simpsonii* hybridise freely where they meet, both occur on the mountains near McKinnon Pass, and × *R. baughani* could be matched in any hybrid swarm.

Ranunculus recens T. Kirk.

The upper leaf surfaces of this small plant are peculiarly pale green, tuberculose, with a single hair at each tubercule, the veins sunken and obvious, the margins more or less ciliate, under surfaces lighter, with the veins evident. Flowers on short stout scapes, single or in clusters of 2–4, sunken amongst the bases of the depressed radical leaves. Heads globose ± 6 mm. diam., achenes green, tipped or marked with purple, drying to red-brown after leaving the receptacle.

Ranunculus rivularis Banks and Sol. ex Forst.

This plant creeps widely underground and epharmones towards a larger growth as it recedes from a wet to a shaded or even open habitat. Plants with minute and almost sessile leaves and flowers, collected from swamps at Woodend, Invercargill, altered in one season of cultivation, in ordinary soil, into long-petioled, large-leaved plants that spread aggressively. One or more of Bentham's varieties may be habitat forms.

Ranunculus acaulis Banks and Sol. ex D.C.

Kirk (1899, p. 18) has a footnote stating that the "creeping scions are almost filiform and often subterranean." All the plants we have seen creep widely below the surface, the stems are always subterranean, white, soft and stoutly fleshy, with soft roots from the nodes. It spreads widely in sand and also in ordinary soils in cultivation.

PITTOSPORACEAE.

Pittosporum fasciculatum Hook. f.

Allan (1928, p. 186), *Index,* is justified in restricting this species to the Volcanic Plateau, North Island. The specimen referred to by Cheeseman (1925, p. 488) as being that of Colenso's *P. viride* (it is labelled *P. viridum*) "which Hooker selected as the type of *P. fasciculatum,*" has fasciculate flowers, smaller than those of *P. colensoi* in the form we are acquainted with at the Southern Lakes, the Fiord Botanical District and Stewart Island, and the bracts, apparently early deciduous, are absent. Matthew's specimen from the Awatere Valley, Marlborough, included here by Cheeseman, has large single flowers and persistent bracts, and it should be referred to the aggregate of *P. colensoi.*

LEGUMINOSAE.

Sophora longicarinata sp. nov.

Arbuscula *S. microphyllae* valde affinis, sed foliis longioribus, foliolis minoribus maltis, breviter petiolatis, praecipue floribus longecarinatis differt.

A small tree to about 5 m. high; older branches reddish-brown, rough by old leaf scars, furrowed and irregularly covered by old pubescence, young branches and petioles, yellow-green, minutely pubescent. Leaves 10–18 cm. long; 1 cm. broad; leaflets opposite or subopposite or alternate, 20–40 pairs, shortly petiolate, small, ± 4 mm. long, 2–2·5 mm. broad; on young plants smaller, obovate cuneate or almost orbicular, dark green and glabrate above, lighter green, most minutely pubescent and keeled below. Flowers lemon colour, ± 5 cm. long, 3–5 on a short stipulate rhachis, stipules small, bluntly rounded; rhachis 2 cm. long, pubescent; pedicels 3 cm. long, deflexed, frequently looped, pale yellow-green, pubescent, calyx 1·5 cm. long, yellow-green, pubescent, with broad, shallow, red-tipped teeth, standard 3·5 cm. long, 2·5 cm. broad; wings 4 mm. longer, 1 cm. broad; keel 1 cm. longer than the standard, linear oblong; stamens unequal, as long as the keel; style equalling the stamens and keel. Pods 5–12 cm. long, irregularly interrupted, 4 winged. Seeds 3–5, oblong, 8 mm. x 5 mm., slightly compressed, pale brown, yellow at the hilum and its margin.

Type specimens in the Herbarium, Plant Research Bureau, Wellington, collected by Mr. A. W. Wastney at Takaka, Nelson.

A fine specimen of this handsome species flowers in October in Mr. E. Stead's garden at Ilam, Christchurch, but the flowering period is later at Takaka. The longer leaves, their many small, dark green, shortly petioled leaflets and long keeled flowers separate it from the many forms of the more widely distributed *S. microphylla.* Mr. Wastney informs us that it occurs between Riwaka and Takaka,

Nelson, and Mr. Owen Fletcher says he has seen it on limestone at Mount Arthur, but we have not seen specimens from that locality. Young plants have smaller leaflets, but no divaricating juvenile form.

Cheeseman (1925, p. 530) has suggested that the plant be named in honour of the late Mr. Treadwell, but it is desirable that attention be drawn to the long keeled character in the flower.

We had prepared a description for a beautiful plant from Haulashore Island, Nelson, as var. *daviesii* of this species, and one for the equally fine plant of Piha, Auckland, as var. *fulvida*, but meanwhile, as the plant from Nelson is dubiously indigenous in its habitat, and the Piha one mingles with and is difficult exactly to segregate as a true breeding entity from the local form of *S. microphylla*, we hesitate to make distinctions. The genus is much in need of study to separate the many forms. We have to thank Mr. William C. Davies, Cawthron Institute, Nelson, for splendid specimens and photographs of the Haulashore Island plant, and Miss B. E. G. Molesworth for specimens of the Piha plant.

MALVACEAE.

Hoheria ovata sp. nov.

H. sexstylosae affinis sed caules pallidiores, folia breviora, subcoriacea, ovata vel late ovata vel nonnumquam lanceolata, subtus pallida nonnumquam aliquantum purpurea, venis conspicuis.

A much-branched spreading tree to 6 m. or more high, glabrous except the tender tips, which are more or less scaly pubescent; bark at the young tips and on short branchlets light or reddish-brown, on older wood greyish, or greyish-green by fissuring, branches slender, spreading. Leaves subcoriaceous, varying much in their shape and size; on short branchlets or on adventitious shoots small, 2–5 cm. long, 2–3 cm. broad, ovate or broadly ovate, or the smaller ones almost orbicular, acute or obtuse; on the main growth larger, 6–8 cm. long, 3–4 cm. broad, ovate acuminate, or sometimes lanceolate, acute or subacute, irregularly and coarsely serrate, green above, greyish-green or purplish beneath with the veins and reticulation conspicuous. Flowers single, or 2–3 in the axils of the leaves, fully 2 cm. diam.; peduncles slender, 3 cm. long, jointed at the lower third, purplish, glandular pubescent; calyx lighter in colour, glandular pubescent, teeth acute; petals white, obliquely ovate, notched on one side below the rounded tip; stamens white, style purplish. Carpels 5–8, silky pubescent, with a membraneous wing at the back.

Habitat: Forest openings and edges in the Nelson Province.

Type specimens from the Kaituna River, near Collingwood, in the Herbarium, Plant Research Bureau, Wellington.

The polymorphy is not confined to plants in the seedling stage, or to small plants, as these may develop large leaves quite early. The small leaves are usually those of small branchlets, and as the branches develop into longer and larger growth the leaves attain their full size. In their shape and in their paler conspicuously veined and often purplish under-surfaces the leaves resemble very closely those of the much larger *H. populnea*.

Kirk (1899, p. 72) may have included it in his supposedly widely distributed *H. populnea* var. *dentata,* but type specimens are not preserved in his herbarium. It differs from *H. sexstylosa* in its paler bark, its shorter, broadly ovate, subcoriaceous, coarsely-toothed leaves, and thin, paler, often purplish, conspicuously-veined under-surfaces. It is a common species in the Nelson Province, and Dr. H. H. Allan informs us that he has seen it in Westland as far south as Cobden, and that may not be the limit of its distribution on the western side. It may be the *H. sexstylosa* recorded from Canterbury, but we have not seen specimens from there.

VIOLACEAE.

Melicytus lanceolatus Hook. f. var. **latior** nov.

Folia 2–2·5 cm. lata, manifeste subflava, lanceolato-oblonga; petala pallidiora apicibus exceptis.

Similar to the type, but with the leaves wider, 2–2·5 cm., less conspicuously yellow-green, oblong lanceolate. Flowers lighter in colour; petals dark purple at the tips only, elsewhere orange coloured.

Habitat: Forest near Dunedin and southward to Bluff Hill, common but localised, near sea-level to 600 m. altitude.

Type from Flagstaff Hill, near Dunedin, in the Herbarium, Plant Research Bureau, Wellington.

MYRTACEAE.

Metrosideros diffusa (Forst.) W. R. Oliv.

Kirk's (1899, p. 162) comments on the leaf shape of the Banksian specimens describe quite well the usual form at Doubtful and Milford Sounds, and no doubt the specimens were collected at Dusky Sound. In forests at the Fiords, plants with white or with pale pink flowers are equally common without other distinctions. Near Dunedin the leaves are smaller and the flowers smaller and white. The juvenile, whether terrestrial or climbing, pushes out wiry roots from closely-placed nodes; adult flowering branches are shrubby divaricating laterals from the ascending stems.

Metrosideros robusta A. Cunn.

Zotov (1939, p. 275) disputes the theory of Kirk (1889, p. 263) that the coalescence of the descending stems and lateral binders of this epiphyte imprisons and destroys forest trees. He states that he has not found evidence of strangulation, and he maintains that the "light demanding" host is destroyed by the intensity of shade thrown by the faster-growing epiphyte. Other observers have suggested to us that root competition may be the destructive agent or a soil reaction set up by the closely matted fibrous roots. Kirk (*loc. cit.*) states that puriri (*Vitex lucens*), to increase its girth, bursts apart the stems of the epiphyte and, if this be accepted, shade can have but little effect on that species. A shade maximum is reached when the epiphyte slightly overreaches the crown of its host; yet the host lives through this crucial period and survives while the epiphyte develops large spreading branches with a high open crown affording a sufficiency of light, more than most trees offer to much of their foliage. No force, indeed, other than compression could cause the distortion that appeared in rimu trunks, cut while still growing,

enclosed and over-topped, from forest near the Kaituna River in North Nelson. These, examined by the authors with Mr. A. W. Wastney, of the State Forest Service, Nelson, had grown deep, full-length, irregular flanges into the spaces afforded by the rounded stems of the epiphyte, and the distorted timber was sound. Growing trees must add to their girth, and girth in this instance had developed in the form of flanging. Nor must it be forgotten that the host is vertically compressed by the upward thrust of its own growth against the throttling increase of the epiphyte at its point of origin, or that the sway of huge superimposed branches in wind must have a disrupting effect.

The theory presented by Kirk is still insufficiently explored, and evidence is lacking as to the incidence of the force or forces causing mortality, but the theory cannot be carelessly dismissed. We are not convinced that shade is the cause of mortality.

ONAGRACEAE.

Epilobium matthewsii Petrie.

This rupestral species was first described by Petrie (1913, p. 266) as *E. arcuatum,* but the epithet was preoccupied, and later (1921, p. 369) he submitted *E. matthewsii.* He admitted having but scanty material, but his leaf measurements, " 2–2½ cm. long, 1–1¼ bread," are quite correct, and the plant could not be recognised from Cheeseman's (1925, p. 617) description, " 1¾ in.–2 in. long, ⅓ in. broad." At McKinnon Pass and the Cleddau Valley, and in upper basins of the Homer River, the leaves never exceed 3 cm. in length, and generally they are shorter. The stems are frequently 25 cm. in length, decumbent and ascending, often branching at the base; the flowers are almost sessile; calyx segments 5 mm. long; petals white, not " pink," 8 mm. long, obovate; stigma clavate; peduncle on ripened capsule elongating to 1·5 cm.; capsule 4 cm. long, drooping. It hybridises freely with *E. glabellum,* common on stony debris.

BORAGINACEAE.

Myosotis pygmaea Col. var. **glauca** nov.

Herba omnino glauca, pilis longis robustis acutis arte appressis, strigosis praedita, floribus 6 mm. longis, 4 mm. diam., calycis lobis lineare-lanceolatis.

Everywhere dull glaucous green and dotted with long, stout, pointed, closely appressed, strigose hairs from wartose thickenings; flowers 6 mm. long when folded, 4 mm. diam. with the limb spread; calyx lobes linear lanceolate, acute or apiculate, wartose and strigose; lobes squatly ovoid-spathulate, subacute.

Habitat: Grassland at Mount Ida.

Type specimens from the base of Mount Ida at 500 m. altitude, in the Herbarium, Plant Research Bureau, Wellington.

SCROPHULARIACEAE.

Hebe menziesii (Benth.) Ckn. et Allan.

A much branched, erect, glabrous shrub to 2 m. or more high; older branches stout, erect, yellow-green, rough by old leaf scars and swellings, leafy toward the tips; young wood at the tips yellowish or yellow-green, conspicuously bifariously pubescent; pubescence

widest above the leaves, narrowing upward; internodes with opposite and alternate shield-like inflations below the leaves, the inflations rounded and bossed at the base. Leaves openly spaced, wide spreading, 2–2·5 cm. long, 6 mm. broad, obovate-oblong, subacute, rounded at the base, shortly petiolate, coriaceous, green or yellow-green and concave above, lighter green below, convex, keeled; margins entire; petiole narrow, 2 mm. broad over a suddenly widened and thickened boss-like base. Racemes simple 2–6 (4) towards the ends of the branches, 3–4 cm. long, finely bifariously pubescent; bracts lanceolate, subacute, membranous or ciliolate at the margins, rounded or keeled at the back, about equalling the calyx. Flowers 1 cm. long, 1 cm. wide with the lobes spread, white; calyx 5 mm. long, 4 partite, light green, segments as the bracts, corolla tube exceeding the calyx about 2 mm., slender, 2 mm. diam., widest at the throat; limb 4-lobed, wide spreading; lobes lanceolate, rounded at the tip; stamens 2, exserted to half the length of the lobes; style longer than the lobes; ovary 2 mm. long, ovoid, slightly compressed. Capsule slightly exceeding the calyx, 6 mm. long, 3 mm. broad, obovoid, subacute, compressed, narrowed to the base.

H. menziesii was described from specimens of a plant discovered by Menzies at Dusky Sound, but it has since ben confused with Nelson and Marlborough plants not nearly related. To the species we refer our specimens from subalpine areas on the western side of McKinnon Pass and the summit of the Longwood Range, and Mr. W. A. Thomson has plants in his garden at Dunedin collected from the hills above Lake Alabaster and the Pyke River, in the watershed of the Hollyford River. Our description is drawn from specimens—now in the Herbarium, Plant Research Bureau, Wellington—collected in fruit at McKinnon Pass and in flower from plants in cultivation.

Hebe buxifolia (Benth.) Ckn. et Allan var. **pauciramosa** Ckn. et Allan × *propinqua* (Cheesem.) Ckn. et Allan.

A low, closely-branched, yellow-green, rounded shrub to about 5 m. high. Branches ± 4 cm. lng, 4 mm. diam. with the leaves on. Leaves 3 mm. long, 2 mm. broad, loosely imbricating, decussate, coriaceous, obovate, subacute, convex above, keeled beneath, sessile by a wide base, smooth and glabrous. Flowers in 2–4 short dense spikes at the ends of the branches and a terminal one, forming a rounded head; bracts 3 mm. × 2 mm. diam., similar to the leaves; calyx 4 mm. long, 2 mm. diam.; segments obovate, obtuse or subacute, unequal. Corolla 1 cm. long, white; tube equalling the calyx, 1 mm. diam.; limb 1 cm. diam. across the spreading lobes; lobes 4 mm. long, ovate to almost orbicular. Stamens 2, exceeding the tube. Capsule 3 mm. long, ovate, compressed.

This is a smaller and more compact plant than Petrie's *Veronica cassinioides,* which Cockayne and Allan (1934, p. 40) regard as *H. buxifolia* × *lycopodiodes,* and it was found it some quantity where the parent species intermingle on a flat ridge at 900 m. altitude on the Garvie Mountains.

Hebe willcoxii (Petrie) Ckn. et. Allan.

This species, which Cheeseman (1925, p. 810) considered "apparently rare in the wild state," is a simple species characteristic of subalpine shrub associations and grass land at McKinnon Pass, at the Upper Cleddau Valley, and the mountains above the Homer and Eglinton Valleys. In lesser amount it occurs in the upper basins of the Routeburn River where the type specimens were collected, but it is again common in the upper basins of the Matukituki River at Hector's Col, Mount French, and other mountains near Mount Aspiring. Apparently its range in the Fiord Botanical District is wide. Wall (1927, p. 253) records it from Lewis Pass, where we did not find it, but where a glaucous plant, probably *H. glaucophylla* Ckn. is common on Mount Technical with *H. traversii* and a bewildering hybrid mixture. *H. willcoxii* is here separated from the earlier described *H. cockayniana*, which species we restrict to the North-Western Botanical District.

Hebe brockiei sp. nov.

Frutex parvus, *H. willcoxii* affinis; rami annotini fusci, hornotini virides, bifariam pubescentes. Folia conqesta, 1–3 cm. longa, 8 mm. lata, late obqvata, subacuta, coriacea, nitentes, supra profunde concava, subtus obscure carinata. Racemi oppositi ex axillis foliorum superiorum orti; bracteae ovato-lanceolatae, acutae, 1 mm. longae, pedicelli breves, calyx 4-partitus, 2 mm. longus, tubum corollae excedens, segmentis acutis, corolla 5 mm. longa, tubus brevis, lobis late ovate-lanceolatis. Capsula late ovata, acuta, 4 mm. longa.

A small, much-branched, spreading, glabrous shrub 20–30 cm. high; older branches dark brown, rough by old leaf scars, leafy towards the tips; tips green, ringed with dark brown at the nodes, bifariously pubescent above the leaves. Leaves closely placed, spreading, 1–1·5 cm. long, 8 mm. broad, broadly obovate, obtuse, abruptly sub-apiculate, narrowed to a sessile base, coriaceous, light shining green and deeply concave above, lighter green, rounded and obscurely keeled beneath; margins yellowish, entire. Flowers in 2 opposite racemes near the tips of the branches; rhachis 2–4 cm. long, slender, purplish, pubescent, with few or many flowers crowded on the upper portion; pedicels short; bracts ovate lanceolate, acute, half the length of the calyx, membranous at the margins; calyx 4 partite, green, 2 mm. long, exceeding the corolla tube; segments ovate lanceolate, acute, with membraneous margins; corolla white, 5 mm. long, tube short; lobes broadly ovate lanceolate, obtuse, stamens ½ the length of the lobes; style longer than the lobes. Capsule broadly ovate acute, 4 mm. long, compressed. Allied to *H. willcoxii*, but a much smaller plant.

Habitat: Grassland on hills between Amuri Pass and Lake Man, at the head of the Doubtful River, Canterbury, at 1200–1500 m. altitude.

Type in Herbarium, Plant Research Bureau, Wellington.

This small shrub is plentiful at the type habitat, where it was discovered by Mr. W. B. Brockie, the enthusiastic collector in charge of the Native Plant Section at the Botanic Gardens, Christchurch.

Hebe ramosissima sp. nov.

Suffrutex, *H. petriei* affinis, sed multo parvior, confertim ramosus, ramulis adscendentibus, foliis tectis; folia basi fere connata, recurvata, 5 mm. longa, 2 mm. lata, late obovata, obtusa, supra concava, subtus obscure carinata, carnosa; spicae ramulis 2–4, terminales, 12 floribus; bracteae 4 mm. longae, obtusae; flores 8 mm. longi; 6 mm. diam.; calyx profunde 4-partitus; corollae tubus 5 mm. longus; lobis ovatis, 3 mm. longis. Capsula ovata, 5 mm. longa.

A prostrate, closely-branched, glabrous, softly woody plant forming closely-matted patches 20–30 cm. diam. Stems 10–20 cm. long, ± 2 mm. diam., heavily marked by old leaf scars, somewhat tortuous, rooting sparingly. Branches ascending, closely uniformly leafy, 7–8 mm. diam. with the leaves on. Leaves closely quadrifariously imbricating, opposite pairs almost connate at the base, wide spreading and recurved, 5 mm. long, 2 mm. broad, broadly obovate, obtuse, narrowed to a sessile base, concave and dark green above, lighter green and obscurely keeled below, fleshy; upper margins dark red, obscurely and coarsely toothed; lower margins finely ciliolate. Flowering heads terminal, about 12 flowered, loose, about 2 cm. long, 1–5 cm. diam., formed of reduced 2–4 flowered spikes. Flowers white, very shortly pediceled, ± 8 mm. long with the lobes spread, 6 mm. diam. across the lobes; bracts 4 mm. long, linear, obtuse, concave above, rounded below, red tipped; calyx 4 partite to the base, 4 mm. long; segments as the bracts; corolla tube longer, 5 mm. long, 2 mm. diam.; lobes 4, ovate, rounded or subacute, 3 mm. long, 1·5–2·5 mm. broad; stamens 2; slightly exceeding the tube; style shorter than or equalling the stamens. Ovary linear, 2 mm. long. Capsule ovate, obtuse, 5 mm. long, 2·5 mm. wide, laterally compressed, didymous.

Habitat: Moist debris on Mount Tapuaenuku, Inner Clarence Basin, Marlborough, 2150 m. altitude.

This small alpine species has some affinities with *H. haastii* and *H. epacridea*, but it appears to be still more closely related to *H. petriei*, which is, however, a very much larger spreading species.

Type specimens in the Herbarium, Plant Research Bureau, Wellington.

Veronica dasyphylla T. Kirk.

As stated by Cockayne and Allan (1927, p. 42) in their discussion on *Hebe dasyphylla*, "This is a distinct but compound species," and in various forms it has a considerable range. Plants of fellfield on the Garvie Mountains and of moist hollows on the Rock and Pillar Range are very similar to those represented by specimens in the Dominion Museum Herbarium collected by Buchanan from Black Peak and Mount Alta and by Speden from the Old Man Range, and minor differences, due to habitat conditions, are to be expected in specimens from widely different localities. The flowers are numerous, solitary and sessile in the axils of the upper leaves, not terminal as in all the descriptions, and they almost conceal the branches when in full bloom. The corolla is large 1–1·5 cm. diam. when spread, sometimes larger, diurnal. The varieties hereunder described are distinct forms, easily separated from those comparable in leaf size and shape with those of the type. Cheeseman erred in including it

in the *Hebe* section in *Veronica*, and Cockayne and Allan (*loc. cit.*), then unaware of its peculiar dehiscence and following his placing, included it in the genus Hebe. In *Pygmaea* also the flowers are axillary and solitary near to the ultimate tips of the branchlets, not terminal.

—— var. **minor** nov.

Typo multo minor, ramulis gracilibus, sparse foliatis; folia 3 mm. longa, 2 mm. lata, ovata; corolla 1 cm. diam., tubus 3 mm. longus, lobis ovato-spathulatis.

Much smaller in all its parts as compared with the type. Branches laxly leafy, 4 mm. diam. with the leaves on, purplish, everywhere dotted with stiff, white, retrose hairs. Leaves small, 3 mm. long, 2 mm. broad, obovate, rounded at the tips, finely pubescent on both surfaces. Corolla 1 cm. diam. when spread; tube 3 mm. long; lobes of the limb ovate spathulate, rounded at the tips.

Habitat: Turfy hollows amongst low grasses and other vegetation on the summit of Mount St. Mary, Kurow, Waitaki Valley.

Type specimens in the Herbarium, Plant Research Bureau, Wellington.

The slender, open, and laxly leafy habit, the small, rounded leaves, and smaller flowers of this plant separate it from all other forms near to the type.

—— var. **subacuta** nov.

Typo minor, ramulis dense foliatis: folia 3 mm. longa, 1 mm. lata, lineari-lanceolata; flores utin var. minore.

Smaller than the type. Branches closely leafy, 4 mm. diam. with the leaves on, purplish, covered with stiff, spreading, or retrose hairs. Leaves smaller, 3 mm. long, 1 mm. broad, linear lanceolate, subacute, slightly spreading, minutely pubescent on both surfaces. Flowers as in var. *minor*.

Habitat: Peaty ridges at Rough Peaks, Lake Wakatipu.

Type specimens in the Herbarium, Plant Research Bureau, Wellington.

Easily separated by its smaller size and by its small linear lanceolate leaves.

We are acquainted with this variety in other parts of the Lake Wakatipu District, and Wall's specimens in the Dominion Museum Herbarium, from Cecil Peak, belong here.

Veronica uniflora T. Kirk.

The small specimens in Buchanan's Herbarium at the Otago University Museum compare quite well with his description and drawing (1882, p. 347) of it as *Logania armstrongii*, and the calyx and ovary are pilose as figured. The type habitat, "Hector's Col, Mount Aspiring, 5000 ft. alt." (Matukituki Saddle of the maps), and the slopes in its near vicinity have been visited by Petrie and others, and by the authors on different occasions, but the plant collected in 1881 has not been rediscovered. Much is still unknown of the vegetation on the steep faces rising to Mount Bevan and Mount Barff from the snow-filled ravine leading up to Hector's Col, and records of the occurrence of the plant at other stations must in the meantime be regarded as doubtful. Buchanan's specimens may

be those of an epharmonic form, but they do not match, even nearly, any specimens or plants of *V. dasyphylla* we have seen. Young leaves have a few stiff pointed hairs standing up from their tips, the flowers are comparatively large, solitary, and sessile, and they appear to be axillary as in *V. dasyphylla* and other small species.

Veronica muelleri Buch.

A slender, prostrate, closely branched, softly woody plant, spreading and rooting to form dense patches 20 cm. or more in diam. Branches short, 2–4 cm. long, leafy tetragonous, 1·5 cm. diam. with the leaves on, ascending; stems slender, purplish, glabrous or with a few thick hairs. Leaves spreading, ·5–1 cm. long, 2–3 mm. broad, oblong or ovate or obovate spathulate, rounded or obtuse at the tip, narrowed to the petiole, almost or quite flat, entire or with 1–3 teeth on each side, glabrous, shining green on both surfaces; leaf tips and teeth with short stout apicals; petioles about ½ the length of the blade, almost connate at the base. Flowers axillary, solitary or branched in pairs; pedicels short, about 1 mm., elongating to about 5 mm. in fruit, glabrous, purplish; bracts at the base of the pedicels, shorter and narrower than the leaves, entire; calyx 4–5 mm. long, divided to the base into 4 equal and open segments, or with 4 equal segments and a short narrow linear segment; equal segments obovate-spathulate, glabrous; corolla pink, 6–7 mm. long, exceeding the calyx 2 mm. or more, ephemeral, 4 lobed, slightly spreading, 4 mm. diam., patent to 8 mm. diam. when deciduous; lobes 2 mm. broad, broadly lanceolate obtuse, the anterior lobe orbicular-spathulate and emarginate, 4 mm. broad and frequently split into 2 narrow segments; tube shorter than the calyx segments, 3 mm. long, 2 mm. diam., whitish; stamens 2, exceeding the tube, ½ the length of the lobes; anthers large, pink, 2 lobed; style slender, equalling the stamens. Ovary 1 mm. diam., conical, slightly compressed, seated on a ringed disk. Capsule obcordate, included in the calyx, 4 mm. long and broad, laterally much compressed, grooved at the septum, splitting simultaneously both loculicidally and septumically into 4 segments in dehiscence.

Habitat: Consolidated moraine, fans and debris slopes in upper basins of the western branch of the Matukituki River at Hector's Col. Altitude 700–1400 m. Specimens have been deposited in the Herbarium, Plant Research Bureau, Wellington. This species is described as a straggling plant with a terminal inflorescence, and the plate shows an elongated corolla tube, 4 lobed wide-spreading limb and a carpel with a didymous dehiscence, but the straggling habit is not apparent, and the stems and branches intermingle closely. The flowers, apparently terminal, are axillary, the corolla tube is distinctly shorter than the calyx, and the lobes spread widely only when deciduous. Buchanan no doubt figured a corolla raised from the receptacle, and assumed the method of dehiscence.

Veronica plano-petiolata sp. nov.

V. muelleri affinis, sed differt ramulis rubicundis pilosis, foliis atris vel rubicundis, petiolis planis, floribus albis, calyce breve piloso.

A slender, prostrate, closely branched softly woody plant, spreading and rooting to form dense patches 20 cm. or more in diam.;

branches short 2–4 cm. long, leafy tetragonous, about 1 cm. diam. with the leaves on; stems ascending, slender, purple, pubescent. Leaves spreading, ± 6 mm. long, 2 mm. broad, ovate-spathulate, subacute, narrowed to the petiole, almost or quite flat, entire or with a stout tooth on each side, somewhat fleshy, glabrous and shining, dark green changing to purple, petiole equalling or shorter than the blade, flat, 1 mm. broad, widening at the almost connate base, reddish.

Flowers axillary, solitary or 2 together; pedicels short, 1 mm. long, slightly elongating in fruit, sparingly pilose, purplish; bracts unequal, the larger one 4 mm. long, oblong-spathulate, entire, green, ciliolate on the margins, the smaller one 1 mm. long, linear, obtuse; calyx 4 mm. long, 4 partite to the base, openly divided; segments linear spathulate, obtuse, outer surfaces pilose; margins ciliolate; tube 2 mm. diam., equalling the calyx; limb white, 4 partite, 8 mm. long, 5–6 mm. diam. across the spreading lobes; lobes almost orbicular, the anterior one emarginate, sometimes split at the centre. Stamens 2, very slender, equally the tube; style slender, equalling the stamens. Ovary minute, globose, seated on a ringed disk. Capsule not seen.

Habitat: Debris slopes and fans on Mount McPherson, head of the Homer Valley, at 1400–1700 m. altitude.

Type specimens, collected by Mr. Owen Fletcher, in the Herbarium, Plant Research Bureau, Wellington.

This plant differs from *V. muelleri* by its reddish, sparsely pilose stems, its dark green or reddish leaves, widish flattened petioles, white flowers, and short, pilose calyx. The large lobe frequently splits at the centre in a manner similar to that of *V. muelleri.*

Veronica laxa sp. nov.

Suffrutex parvissimus, graclis parce ramosus, prostratus; ramuli 3–4 cm. longi, tenues, nonnihil purpurei, sparse pubescentes, pilis subpatentibus; folia 6–10 mm. longa, 4–6 mm. lata, late ovata vel fere orbiculata, nonnumquam obovata, 1–3 dentata vel integra; flores in axillis ramulorum, solitarii vel 2 conjunctim; bracteae 6 mm. longae, 3 mm. latae, obtusae, calyx 6 mm. longus, profunde 4-partitus, pubescens, segmentis obtusis; corolla alba, 8 mm. longa, 8 mm. diam., tubus calyce brevior, 4 mm. longus, lobis orbiculatis. Capsula obcordata, 4 mm. longa.

A slender, prostrate, laxly-branched, semi-woody plant, spreading and rooting to form loose patches 20 cm. or more diam. Branches short 3–4 cm. long, slender, purplish, thinly pubescent, with short, spreading, upturned hairs. Leaves varying greatly in size and shape 6–10 mm. long, 4–6 mm. broad, broadly ovate to almost orbicular or sometimes obovate, irregularly 1–3 toothed or lobed, or occasionally obovate spathulate and entire, rounded at the tip or subacute, rounded or narrowed to the petiole, fleshy, most minutely pubescent; petiole about half the length of the blade, narrow, flat, thickened and almost connate at the base. Flowers in the axils of the branches, solitary, or 2 together; bracts 6 mm. long, 3 mm. broad, obovate spathulate, obtuse; petiole 2 mm. long, purplish, pubescent; calyx 6 mm. long, 4 partite to the base, pubescent as the leaves; segments obovate spathulate, obtuse, entire or with one shallow notch at each side; corolla white, 8 mm. long, 8 mm. diam. with the limb spread, tube

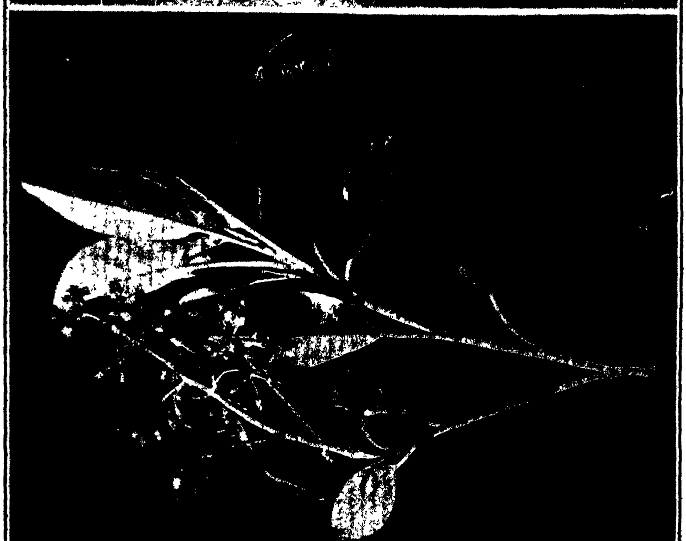

FIG. 1.—*Senecio bennettii.*

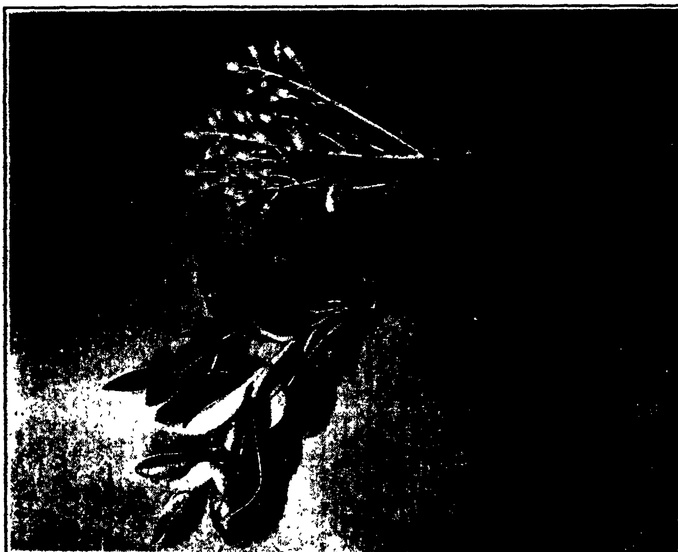

FIG. 2.—*Senecio cockaynei.*

shorter than the calyx, 4 mm. long, 2 mm. diam.; lobes 4, orbicular, 2 mm. broad; stamens 2, equalling the calyx; style equalling the stamens. Capsule obcordate, 4 mm. long, 4 mm. broad, laterally compressed, included in the calyx, dividing into 4 valves.

Habitat: Fine debris amongst rocks of moraine on the floor of the Homer Valley basin, near the tunnel, with *Myosotis lyallii*, at 800 m. altitude.

This plant was discovered by Mr. Owen Fletcher in 1939, and Mr. Coombs' specimens, now in the Herbarium, Plant Research Bureau, Wellington, have fruits and a few late flowers.

CAMPANULACEAE.

Pratia perpusilla Hook. f.

Flowers are shortly stalked, 1 cm. long, 8 mm. diam. across the spreading lobes; calyx 5 mm. long, everywhere covered with short white bristly hairs; segments 2 mm. long, narrow, subulate, persistent. Berry ±, 3 mm. diam., globose, green, indehiscent. Seeds numerous, minute, broadly oblong, brown. Hooker included this plant in *Pratia* with the reservation "Fruit not seen." Our specimens in the Herbarium, Plant Research Bureau, Wellington, were collected at the end of March, 1941, from hollows in fixed dunes at Wickliffe Bay, Otago Peninsula.

COMPOSITAE.

Olearia capillaris (T. Kirk) Ckn. et Allan × **lacunosa** Hook. f. = *O. sauvis* Cheesem.

O. capillaris is a small-leaved tree with papery-barked tortuous branches and on Mount Arthur it is found near streams with *O. lacunosa*. The species hybridise freely and they produce a curiously diverse progeny. This origin for Cheeseman's species, rather than *O. arborescens* × *lacunosa* as listed by Cockayne and Allan (1934, p. 50), was suggested to us by Mr. F. G. Gibbs prior to our visit to the mountain.

Olearia avicenniaefolia (Raoul) Hook. f. × **Celmisia du rietzii** (Ckn. et Allan) Martin.

A branching, leafy, woody shrub to ·5 m. high, with the branches, scapes and petioles purplish and finely pubescent, branches 4–5 mm. diam., covered with the older withered leaves. Leaves alternate, 7–10 cm. long, 1·5–2 cm. broad, oblong, petiolate, gradually narrowed to the petiole, narrowly rounded at the tip, thin and flaccid, light shining green above, finely pubescent and somewhat viscid; pale with a bluish-white, closely-appressed tomentum beneath, the purplish midrib prominent, and the veining evident; margins sinuate between small, green, distantly-spaced hydothodes; petioles 2 mm. diam., grooved above, rounded beneath, ± 1·5 cm. long, with a short sheathing base 5 mm. broad. Scapes 2–3 to each branch from the axils of the lower leaves, 6 or more flowered, 20 cm. long, less than 2 mm. diam., peduncles alternate from obovate spathulate cauline leaves, variously lengthened to form a laxly corymbose inflorescence, naked or with one or more small linear pubescent bracts. Heads 2·5 cm. diam., involucre oblong, rounded at the base, 6 mm. long, 4 mm. diam.; involucral scales in 3 unequal series, ovate lanceolate, acute, pubescent, membraneous or finely ciliate at the margins; ray florets

in 2 series, white, 1·8 cm. long, 3 mm. broad, linear obovate, rounded at the tip; disc florets with 5 triangular pointed reflexed lobes. Achenes 2 mm. long, linear, terete, or slightly compressed, scabrid. Pappus hairs strict, scabrid, shorter than the florets.

This puzzling hybrid was discovered by Mr. James Speden, of Gore, on hillsides above the Hostel at Arthur Pass Township, and he has kept it in cultivation. Specimens in the Herbarium, Plant Research Bureau, Wellington, are from Mr. Speden's plant, and cuttings from it are in cultivation.

It is not possible to be certain of the parentage, and attempts at seed germination have as yet been unsuccessful, but the parents we have nominated are extremely common where the plant was discovered, and its growth and general appearance are such as might be expected from their cross.

Celmisia ramulosa Hook. f. var. **tuberculata** nov.

Folia semi-patentia, angustiora, rigidiora, crassioraque quam in typo, marginibus revolutis, fere ad costis; pagina superiora tuberculata; bracteae involucris rubicundae apice versim; ligulae lineare-oblongae, obtusae, apicibus incurvis.

Adult leaves semi-patent, narrower and more closely imbricating, rigid, and coriaceous than those of the species; margins strongly revolute; under surface tomentose; upper surface and margins tuberculate and dotted with stout hairs. Flowers with longer and slender peduncles; peduncles ± 5 cm. long, purple, covered with stiff hairs; bracts swollen at the base, involucral bracts red tipped; ray flowers linear oblong, 1·5 cm. or longer, 2 mm. broad, obtuse, thickened and incurved at the tip.

The variety is common on many of the mountains on the eastern side of South Island, where it replaces the more showy form of the western districts, and no doubt it is the form with patent leaves mentioned by Cheeseman (1925. p. 936) as sent to him by Cockayne.

Type specimen from Rough Peaks. Lake Wakatipu, in the Herbarium, Plant Research Bureau, Wellington.

Celmisia haastii Hook. f. var. **tomentosa** nov.

Omnino ut in typo, extra tenuem chartaceum tomentum superiore pagina.

Similar to the type in shape and habit, but the upper surface white with a thin papery tomentum.

Habitat: Moist slopes near runnels on the Rock and Pillar Range, Otago, 1200–1500 m. altitude.

Type specimen in the Herbarium, Plant Research Bureau, Wellington. The plant spreads close on the ground to form patches of considerable size, exactly in the manner of the species, and its white upper surface is conspicuous at some distance.

Celmisia polyvena sp. nov.

Suffrutex parvus, caulibus firmis: folia subpatentes, 6–7 cm. longa, 3–4 mm. lata, linearia apice obtusa, subcoriacea, supra subtusque dense tomentosa, costis venisque prominentibus; vaginae

3–4 cm. longae, 8–10 mm. latae, tenues, tomentosae; scapi 10–15 cm. longi, graciles; bracteae numerosae, lineari-lanceolatae, argenteo-tomentosae. Capitula non visi.

A small laxly-tufted plant forming patches to ·5 m. diam. Stems stout, 1–2 cm. diam. with the leaves on. Leaves spreading, 6–9 cm. long, 3–4 mm. broad, linear, narrowed to an obtuse tip, wrinkled above, thickened at the base, subcoriaceous, densely cottony tomentose on both surfaces; with the midrib branching in veins to the margins, prominent; sheaths 3–4 cm. long, 8–10 mm. broad, thin, woolly tomentose. Scapes 10–15 cm. long, slender, with many linear, lanceolate, silvery tomentose bracts. Heads not seen.

Habitat: Peat slopes with *Oreobolus* and other bog vegetation.

Type specimen from Table Hill, Stewart Island, in the Herbarium, Plant Research Bureau, Wellington.

In recording this plant as *C. linearis*, Cockayne (1909, p. 63) mentioned the conspicuously veined under-surface of the leaves and the "closely leaved flower bud," and he recorded another closely allied but smaller plant on Mount Rakiahua.

C. polyvena is probably an endemic of Stewart Island, and its characteristic veining separates it from any other species we are acquainted with. We have not seen the smaller plant recorded by Cockayne.

Celmisia clavata sp. nov.

C. sessiliflorae aliquantalum affinis, sed ramulis clavatis, foliis erectis, rigidis, arte imbricatis, differt. Suffrutex ad 10 cm. altus; ramuli foliis annotinis vestiti, clavati, arte foliati; folia linearia, 6 mm. longa, vix 1 mm. lata, striata, basim varsus purpurea; capitula 1·5 cm. diam., terminalia, foliis circumdata; bracteae ± 25, subaequales, lineari-lanceolatae; achenia pubescentia.

A semi-woody, branching plant to 10 cm. high, forming loose patches 10–30 cm. diam.: branches clothed with the remains of old leaves, rebranching closely at the tips; branchlets 3 cm. long, 1 cm. diam. with the leaves on, clavate, rounded at the tips, most densely leafy. Leaves linear, 6 mm. long, less than 1 mm. broad, erect, rigid, and closely imbricating, irregularly thickened and ridged on both sides, suddenly and bluntly pointed, silvery by a fine silky tomentum; base membranous, purplish, rather longer and broader than the blade, more or less woolly tomentose. Heads 1·5 cm. diam., terminal, solitary, sunken amongst the uppermost leaves, involucral bracts ± 25, about equal, linear lanceolate, membranous, silky at the tips. Ray florets few. Achenes silky.

Habitat: Peat bogs on the mountains of Stewart Island.

Type specimen from Table Hill, Stewart Island, in the Herbarium, Plant Research Bureau, Wellington.

C. clavata, probably a Stewart Island endemic, has been variously recorded as *C. sessiliflora* or *C. argentea*, but its semi-woody character, its densely leafy clavate branches, and its erect, rigid, closely-imbricating leaves, are very distinct and not to be confused with those of any other species.

Raoulia petriensis Kirk.

Kirk's description (1877, p. 549) and that of Cheeseman (1925, p. 974) could be taken as describing different plants; Kirk's a "hard, densely tufted species," and Cheeseman's "Forming laxly branched patches." In the original habitat—Mount St. Bathans—and on Mount Ida the branches are very hard, but laxly branched, and Kirk would be deceived by a close branching of new shoots from the tips of the specimens collected by Petrie. The branches are 4 mm. diam., the leaves 6 mm. × 3 mm., rather widely spaced, closely appressed to the stem, deeply concave and woolly above, rounded beneath and the tips spreading, thick and coriaceous.

The branches of our specimens from the Kurow Mountains are smaller, ± 3 mm. diam., and they remain slender in cultivation.

Helichrysum selago var. **tumida** Cheesem.

Cheeseman's description is brief: "Branches stout, almost matching those of *H. coralloides*," but the branches of *H. coralloides* are ± 7 mm. diam., those of *H. selago* ± 2 mm. and of var. *tumida* ± 4 mm. The leaf series and the inflorescence of *C. selago* and of var. *tumida* are much alike, the flower heads of both are 5 mm. long, that of the species 3 mm. diam. at the involucre, exceeding the diameter of the branches, and of var. *tumida* 4 mm., equally the branches. *H. coralloides* and *H. selago* var. *tumida* are in no manner alike.

Senecio bellidioides Hook. f. var. **orbiculatus** nov.

Herba glabra; folia omnino radicalia, 6 cm. longa vel longiora, ± 3 cm. lata; petioli crassi, virides, vaginis purpureis, laminis orbiculatis, subcoriaceis, supra nitentibus, rugosis, subtus pallidioribus venis prominentibus.

A bright green, glabrous semi-coriaceous plant; rootstock stout, rhizomatous, closely rooted, covered by the remains of earlier leaves, branching to form dense clumps. Leaves radical, 6 cm. or more long, more or less 3 cm. broad; petiole stout, 3 mm. broad, as long as or much longer than the blade, green, grooved above, rounded beneath, widened to a purplish sheathing base ± 8 mm. broad; blade orbicular, quite glabrous, subcoriaceous, shining green above, rugose by sunken veining, obscurely sinuate at the margins between many inconspicuous pale brown hydathodes; lighter green below and the midrib and principal veins prominent. Scapes one or two, 1 flowered, 10–15 cm. long, fully 1 mm. diam., reddish, thinly pubescent, with 6–10 linear lanceolate acute bracts. Heads ± 3 cm. diam., involucre oblong, rounded at the base, 7 mm. diam.; bracts in 2 series, linear oblong, membranous at the margins, subacute; ray florets 2 cm. long, 4 mm. broad, obovate-oblong, 2–3 toothed at the tip, bright yellow. Achenes linear, terete, rounded at the base, truncate at the tip, striate, glabrous; pappus hairs scabrid.

Habitat: Grassland and subalpine scrub on the Garvie Mountains at 1200–1500 m. altitude, common.

Type specimen in the Herbarium, Plant Research Bureau, Wellington, collected from the type habitat.

—— Hook. f. var. **setosus** nov.

Herba rhizomata, omnino dense setose-pilosa; folia radicalia 6–10 cm. longa, 3–5 cm. lata, laminis late ovatis vel obovatis, marginibus incrassatis.

A light green, softly-leaved plant, everywhere densely clothed with setose glandular hairs, rootstock stout, 1 cm. diam., rhizomous, closely rooted, rough by old leaf scars. Leaves radical, 6–10 cm. long, 3–5 cm. broad; petiolate stout, ± 3 mm. wide, as long as the blade, purple or purplish, deeply grooved above, rounded beneath, widened to 1 cm. at the base, prominent under the blade; blade broadly ovate or obovate, rough above by sunken reticulations, closely obscurely lobed; margins thickened, pale brown; hydathodes many, dark brown, evident; under surface reticulation prominent. Scapes several from the axils of the lower leaves, 1 flowered, 10–15 cm. long, stout, 2 mm. diam., reddish, with 4–5 linear obovate spathulate bracts. Heads ± 3 cm. diam.; involucre broadly obconical, 1 cm. diam.; bracts in 2 series, numerous, linear oblong, rounded at the tips; ray florets 1·5 cm. long, 2 mm. broad, round tipped, bright yellow, red-brown below. Achenes terete, rounded at the base, truncate at the tip, striate, glabrous; pappus hairs scabrid.

Habitat: Subalpine scrub and grassland on Mount Fyffe, Kaikoura Mountains.

Type in the Herbarium, Plant Research Bureau, Wellington.

Senecio cochlearis sp. nov.

Herba usque ad 40 cm. alta; radices incrassatae; folia omnino radicalia, 15–30 cm. longa, laminis 3–20 cm. longis, 2–4 cm. vel ultra latis, anguste-ovatis vel ovatis, basi rotundatis vel subtruncatis vel fere cordatis, marginibus incrassatis, ciliatis, supra strigose-pilosis pubescentibusque; scapi 20–30 cm. longi, scabridi, ramosi; bracteae lineares vel lineari-ovatae, 1–5 cm. longae; capitula ± 3 cm. diam., bracteus linearibus, pubescentibus; ligulae lineares, obtusae, 2·5–3 cm. longae; achenia linearia, 2 m. longa, glabra.

A herbaceous plant; rootstock short, stout, clothed with the fibrous remains of old leaves, closely and deeply rooted. Leaves radical, 15–30 cm. long; blade as long or much longer than the petiole, varying in shape and size, 3–20 cm. long, 2–4 cm. or more broad, ovate, or more usually linear ovate, obtuse or subacute, rounded, or almost truncate, sometimes cordate at the base and usually unequal, thin, pale green on both sides or sometimes purplish beneath, the under-surface veins purplish and evident, and the midrib prominent toward the base; margins thickened or recurved, ciliate, sinuate, sometimes with a few coarse teeth, the hydothodes dark and prominent or rather long; upper surface dotted with stoutly pointed, jointed, and strigose bristles interspersed with finer ones, slender; petiole purplish, more or less coarsely pubescent and dotted with purplish bristles. Scapes 20–30 cm. long, green or purplish, scabrid, branched, 4–6 flowered; bracts linear or linear ovate, 1–5 cm. long, 1–3 mm. broad. Heads ± 3 cm. diam.; involucral scales linear oblong, coarsely pubescent; ray florets linear, obtuse, 2·5–3 cm. long, 2 mm. broad; disc florets tubular; pappus hairs scabrid. Achenes linear 2 mm. long, ribbed, glabrous.

Type specimens in the Herbarium, Plant Research Bureau, Wellington, collected from banks at road cuttings westward of the Ohikinui River, Lower Buller River Valley, Nelson.

Senecio scorzoneroides Hook. f.

Cheeseman (1925, p. 1015) refers to the ray florets as " variable in colour, white to yellow or pale-salmon." The florets are invariably white, sometimes " pale salmon " in withering, and in hybrid forms with *S. lyallii* they are usually more or less lemon coloured.

Senecio cockaynei sp. nov.

S. rotundifolio similis sed caulibus fragilibus, purpureis, inflorescentiis virgatis differt. Frutex ramosus, ramis aetate glabris, subangalatis; folia petiolis pubescentibus; 1–2 cm. longis, laminis 4–6 cm. longis, 3–4 cm. latis, oblongis vel obovatis, obtusis, basim versus angustatis supra glabris, subtus appresse-tomentosis; panicula rigida, ramulis dense tomentosis; bracteae inferiores foliatae; ± 3 cm. longae, superiores parvae ad minutae; capitula cylindrica, 1 cm. longa, 4 mm. diam., bracteis lineari-lanceolatis; achenia linearia, striata, pilosa.

A small, softly-woody shrub to about 1 m. high, branching from the base. Branches erect or spreading, brittle, bronze-green or purplish, glabrous or unevenly matted with the remains of early pubescence, ribbed in decurrent lines from the bases of the alternate leaves; young tips finely pubescent. Leaves with pubescent grooved petioles 1–2 cm. long, base swollen, reddish, blade 4–6 cm. long, 3–4 cm. broad, oblong or obovate, rounded or obtuse at the tip, or the young leaves subacute, narrowed to and usually unequal at the petiole; upper surface green and glabrous; under surface with the midrib prominent, clothed with a thin, closely appressed, silvery or greyish tomentum barely concealing the veins and the reticulation; margins obscurely toothed and repand; youngest leaves fulvous. Panicles rigid, terminating the older branches, densely woolly tomentose near the tips and on the inflorescence, unevenly so towards the base; lower bracts leafy ± 3 cm. long. 1 cm. broad, upper ones reducing to almost minute towards the tips. Pedicels rather slender, 1 mm. diam., ·5–2 cm. long or sometimes longer, bracteolate. Heads cylindrical or slightly narrowed towards the top, 1 cm. long, 4 mm. diam.; receptacle discoid, pitted; involucral bracts 8, linear-lanceolate, acute or subacute, naked, shining and concave within, tips reddish, margins membraneous; female florets 0; disc florets about 20; limb companulate, deeply 5 lobed. Achenes capitate, rounded at the base, linear, 3 mm. long, grooved, pilose. Pappus hairs scabrid.

Habitat: Coastal stations at Westhaven, West Wanganui Inlet, Nelson. Specimens of this species deposited in the Herbarium of the Plant Research Bureau, Wellington, are from plants in cultivation, collected at the type habitat.

Cockayne (1918, p. 183) in part described this plant from specimens without flowers collected by Mr. B. C. Aston at Westhaven. Its brittle purplish stems and its stiffly erect branching inflorescence are very distinct.

Senecio bennettii sp. nov.

S. elaeagnifolio aliquantum similis, sed foliis apice versus angustatis, nitentibus, subtus parce tomentosis, paniculis laxe ramosis. Frutex (vel arbuscula) ad 3 m. altus, ramulis hornotinis appresse tomentosis; petiolils 5 cm. longi; laminae 5–10 cm. longae, 3–5 cm. latae, elliptico-oblongae, subcoriaceae, supraglabra, subtus tomentosae, venis distinctis; panicula 25 cm. longa; bracteae inferiores ± 5 cm. longae, superiores fere fili formes; capitula 1–5 cm. longa, discoidea, bracteis lineari-lanceolatis; achenia linearia, striata, pilosa.

An erect or spreading, closely-branched shrub or small tree to 3 m. high. Branches ribbed in decurrent lines from the bases of the alternate leaves and, with the petioles, under-surface of the leaves and the inflorescence, densely clothed with a thin closely appressed whitish tomentum. Leaves on grooved petioles 2·5–5 cm. long from a dark green swollen base; blade 5–10 cm. long, 3–5 cm. broad, elliptic-oblong, abruptly narrowed to the tip, obtuse, narrowed to and usually unequal at the petiole, obscurely repand, concave, subcoriaceous, glabrous and shining dark green above with the veins evident, midrib and slender veins prominent below and the reticulation visible through an appressed and shining grey or silvery tomentum; petioles about half the length of the blade, swollen and green at the base. Panicles terminal, rather slender, ± 5 mm. diam. at the base, 25 cm. long, laxly pyramidally branched at leafy bracts. Bracts at the lower branches of the panicle narrowly leafy, ± 5 cm. long, 5 mm. broad, with a petiole as long as the blade or longer; upper bracts reducing in size and the upper ones almost filiform, 1 cm. long. Pedicels 1–1·5 cm. long, bracteolate. Heads truncately conical ± 1·5 cm. long, 6 mm. diam. at the base, narrowed to about 4 mm. at the top, discoid; receptacle pitted; involucral bracts 10–12, linear-lanceolate, semi-acute, naked, shining and concave within, patent after the achenes are shed; female florets 3–5, tubular, with the mouth notched; disc florets 25–30 with a campanulate deeply 5 lobed limb. Achenes linear, capitate, ribbed, 3 mm. long, rounded at the base, pilose; pappus hairs scabrid, spreading, about 4 mm. long.

Type specimens—from upper forest margins, Mount Cargill, near Dunedin—600 m. altitude, in the Herbarium, Plant Research Bureau, Wellington.

The larger shrubby Senecios of South Island and Stewart Island, hitherto recorded in the literature as *S. eleagnifolius*, are not yet sufficiently known, and *S. bennettii* must meanwhile be regarded as a composite of two or more closely-related forms. The plant described and figured is found at upper forest margins on the eastern side of the divide, and a closely-related form with obovate and frequently much larger leaves fringes also the coastal rocks of the western fiords and the near tidal banks of the Rakiahua River, Stewart Island.

We have not seen *S. eleagnifolius* in South Island, and *S. bennettii* differs from that species in its narrower, dark green, shining leaves, their thinly tomentose under surfaces, and in its laxly branched terminal panicles. It is named in honour of Mr. H. Bennett, of Broadacres, North-East Valley, Dunedin, who first drew our attention to its distinct characters.

S. rotundifolius (Forst. f.) Hook. f. var. **ambiguus** Cheesem.

Cheeseman's (1925, p. 1026) reference to Cockayne's (1918, p. 183) opinion regarding the affinities of this plant is irrelevant, as that author's notes concerned the much smaller and very different *S. cockaynei* of this paper.

The description unquestionably indicates the Cape Foulwind plant which we have seen in its habitat, and Dr. W. McKay, who has it in cultivation at Greymouth, knows of its occurrence southward along the coast to Barrytown. Cheeseman's (*loc. cit.*) description is brief, but sufficient for identification. At Cape Foulwind it is 2–3 m. high, with thick, sub-coriaceous leaves 15–20 cm. long, 6–8 cm. broad, obovate or more usually broadly obovate, usually repand, narrowed to a stout petiole half the length of the blade.

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The Orsillini of New Zealand.
(Hemiptera, Lygaeidae.)

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(Communicated by Dr. D. MILLER.)

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INTRODUCTION.

THE tribe Orsillini contains the nearly cosmopolitan genus *Nysius* Dallas (1852) and about twenty additional genera which are more or less restricted to particular islands or continental regions. The most unique types of Orsillini, as of many other groups, are found in Hawaii, New Zealand, and the Galapagos. I have recently monographed the Hawaiian Orsillini (1941), recording a total of eighty-seven distinguishable forms which pertain to five different genera. All but one of these genera are confined to the Hawaiian Islands and all of the species are unique. This work was possible only after years of diligent collecting by various entomologists followed by one year of intensive work of my own. From the remarkable diversity exhibited by the limited number of specimens at hand, it appears likely that the New Zealand Orsilline fauna will prove to be just as unique, though possibly somewhat smaller, than that of the Hawaiian Islands. Moreover, it would appear that our knowledge of these aberrant and possibly primitive forms has scarcely reached the stage which the Hawaiian fauna passed with the death of G. W. Kirkaldy in 1910.

HISTORY.

The first New Zealand species of Orsillini was described by Fabricius (1794) as *Lygaeus clavicornis* from material labelled "Selandia" and mistakenly assumed to be from "Hafniae" on the Danish island of "Selandia." *Clavicornis* was later removed to *Coreus* (Fabricius, 1803), but inasmuch as there was already a *Coreus clavicornis* proposed as new on a previous page of the same work, Fabricius renamed this last as *typhaecornis* in his "emendanda." *Strobilotoma typhaecornis* (Fabr.) is now a well-known European Coreid. The New Zealand Lygaeid was later described by Dallas (1852) as *Nysius zealandicus* and was made the type of a new sub-genus, *Rhypodes*, by Stäl (1868). Buchanan-White added two more species, *Nysius anceps* and *huttoni* in 1878. Here the matter rested for a half a century until Evans, (1929a) reviewed "the genera included under *Nysius*, auctt.," made *Nysius anceps* the type of a new genus, *Hudsona*, and made *clavicornis* Fabr. (= *zealandicus* Dallas) the type of a new genus *Myersia*. Soon after this, *Myersia* was sunk as a synonym of *Rhypodes* (1929b) because their genotypes are identical. Thus we have, at present, three described species, one belonging to the cosmopolitan genus *Nysius* and one each belonging to the endemic genera *Rhypodes* and *Hudsona*.

The present paper deals with a collection of eighty-eight specimens received from Messrs. W. E. China (British Museum of Natural History), H. G. Barber (United States National Museum) and G. V. Hudson. Much of this material was collected by the accomplished Hemipterist, J. G. Myers, from 1921 to 1923, and by G. V. Hudson from 1921 to 1938. This collection contains not only fine series of the three previously known species, but also representatives of five additional species which are described below. Several uniques probably represent still different species, but it seems best to be conservative in the description of new species at this stage. Further field work will doubtless reveal many important additions to this remarkable fauna.

Taxonomy.

The New Zealand Orsillini are so peculiar that no relatives of the endemic genera are known from elsewhere. *Nysius huttoni* Buchanan-White, however, is allied to the Hawaiian *blackburni* Buchanan-White and to *Nysius baeckstroemi* Bergroth from Juan Fernandez. The new genus, *Brachynysius*, is apparently a remarkable off-shoot from typical *Nysius*. Stäl originally separated *Rhypodes* as a subgenus because of the sublateral lobes on the posterior margin of the pronotum. It now appears doubtful if this character is even of specific value, but I have retained the generic name for its type, *clavicornis* (Fabr.), which is obviously of a different stock from typical *Nysius*. The other species described below, e.g., *myersi, stewartensis, chinai,* and *sericatus,* differ so considerably from the genotype that, according to standards elsewhere in the world, each should perhaps be made the type of a new genus. However, I have chosen to lump these together with *zealandicus* into a single, possibly unnatural genus, until further material is at hand and more extensive field work has been done.

Key to the Genera and Species of Orsillini of New Zealand.

1. Hemelytra reduced to short pads which reach only a short distance on to base of abdomen, nearly as broad apically as long, 13 : : 15, the corium definitely delimited, subtriangular, with veins distinct; membrane very short, one-tenth as long as hemelytra. Antero-lateral angles of pronotum produced laterally as small tubercles.	*Hudsona anceps* (Buch.-White)
Hemelytra larger, usually exceeding tip of abdomen. Pronotum without minute antero-lateral tubercles	 2
2. Hemelytra distinctly convex, costal margins strongly rounded beyond basal fourth. Membrane small, exceeding level of apices of coria by less than one-fourth the total length of membrane, without apparent veins	*Brachynysius convexus* n.gen. and sp.
Hemelytra subflattened, the costal margins not strongly rounded. Membrane much larger, extending beyond level of apices of coria for a distance almost half the total length of membrane, veins distinct ..	 3

3. Bucculae decreasing only slightly in height posteriorly, reaching to base of head. Size small, less than 4 mm.	*Nysius huttoni* Buch.-White	
Bucculae decreasing in height at level of antenniferous tubercles, not reaching base of head. Size larger, over 5 mm. ..	Genus *Rhypodes* ..	4
4. Ground colour ferrugineous with black markings. Head and pronotum very coarsely punctured, the punctures of pronotal disk less than one puncture width apart. Hind margin of pronotum more or less distinctly produced sublaterally into rounded or subtriangular plate-like lobes ..	*Rhypodes clavicornis* (Fabr.)	
Ground colour pale, ochraceous, marked with fuscous or black. Head and pronotum less coarsely punctate, the punctures either shallow or separated by more than one puncture width. Hind margin of pronotum without sublateral lobes ..	.. .. ..	5
5. Last two antennal segments subequal in length. Sides of pronotum straight ..	*Rhypodes sericatus* n.sp.	
Fourth antennal segment distinctly longer than third. Sides of pronotum swollen at level of callosities	.. .. ..	6
6. Antennae short and thick, the second segment about four-fifths as thick at middle as front tibiae basally. Body subflattened above, the head and pronotum only feebly declivous. Clavus and corium in great part pale, ochraceous	*Rhypodes myersi* n.sp.	
Antennae more slender, the second segment scarcely more than half as thick at middle as front tibiae basally. Body not noticeably flattened above, the head and pronotum more strongly declivous. Clavus and corium extensively marked with brown	.. .. ..	7
7. Body nearly three times as long as broad. Head and pronotum moderately declivous. Female genital cleft deep, the fourth and fifth visible ventral segments concealed beneath third at middle	*Rhypodes chinai* n.sp.	
Body shorter and very robust, about two and one-half times as long as broad. Head and pronotum strongly declivous. Female genital cleft shallow, both fourth and fifth ventral segments exposed at middle ..	*Rhypodes stewartensis* n.sp.	

Hudsona anceps (Buchanan-White).

Nysius anceps Buch.-White, *Ent. Month. Mag.*, 15: 32–33, 1878.

Hudsona anceps, Evans, *Bull. Ent. Res.*, 19: 353, 1929.

One male is at hand from the British Museum, Otago, New Zealand, Pascoe Coll., determined by Buchanan-White. Five other specimens are from the collection of H. G. Barber as follows: one male, Darfield, New Zealand, August 15, 1923, J. G. Myers; two females, Taitapu, September 2, 1921, J. W. C.; one female, Governor's Bay, New Zealand, November 8, 1922, on grass, J. G. Myers; and one female, Methven, November, 1911. The series is remarkably uniform in size and coloration except for the usual sex differences.

Genus Brachynysius Usinger, nov.

Short, posteriorly broadened; with the pronotum scarcely declivous and the head strongly declivous above as seen from the side; clothed above on pronotum, scutellum and coria with long, erect or backwardly directed hairs. Head as in typical *Nysius*, transverse, vertex moderately finely, evenly punctate; antenniferous tubercles only slightly, subacutely produced at exterior angles; bucculae prominent, gradually decreasing in height posteriorly and abruptly ending before posterior margin of head. Antennae as long as head, pronotum and scutellum together, the first segment shortest, third a little longer, and second and fourth segments longest, subequal. Rostrum reaching to posterior coxae, the first segment not attaining base of head. Hemelytra with sides a little dilated and sinuate at base, then strongly dilated and rounded to apex of membrane; strongly convex except for flattened or feebly reflexed emboliar region; clavus and corium entirely opaque with a row of coarse punctures along claval suture and a few coarse punctures at base of emboliar suture; membrane very small, extending beyond level of apices of coria for only one-fourth its total length, without apparent veins. Ostiolar canal extending to about middle of metapleuron, widened or lobate and rounded but not elevated at apex. Posterior margin of metapleuron broadly lamellately produced and feebly reflexed, the postero-lateral angle feebly, subacutely produced. Legs unarmed.

Genotype: *Brachynysius convexus* Usinger, new species.

Closest to such atypical members of the genus *Nysius* as *huttoni* Buch.-White and *blackburni* Buch.-White, but differing from these as well as all other Orsillini known to me in the geocoroid convexity of the hemelytra and the smooth membrane.

Brachynysius convexus Usinger, new species.

Head a little broader, including eyes, than long, 15 : : 11; extending well beyond middle of first antennal segment; eyes a little less than half as wide as vertex. Proportion of antennal segments one to four as 5 : 9 : 6 : 9. Pronotum a little shorter than head on median line, 10 : : 12; subtrapezoidal; strongly transverse, being five-sixths as long on median line as broad anteriorly and two-thirds as broad anteriorly as posteriorly; disk elevated, impunctate on broad callosities, narrow anterior margin, broader posterior margin and humeri, elsewhere coarsely punctured, the punctures separated by one or more puncture-widths; lateral margins non-carinate, a little rounded anteriorly and feebly sinuate behind callosities. Scutellum broader than long, 11 : : 8, with the usual "Y"-shaped laevigate elevation, elsewhere with a few very coarse punctures. Disk of clavus and corium distinctly coriaceous, very irregularly spotted with dark dots or pseudopunctures on the pale areas.

Colour black with ochraceous apex of clypeus and more or less interrupted median line on head and pronotum, fuscous or lighter posterior lobe of pronotum and humeri, ochraceous tip of scutellum, brown hemelytra with yellowish base and apex of clavus and rather broad yellow areas adjacent to outer and apical margins of corium. Apical margin of corium and membrane, except at extreme apex where it is dark brown, black. Bucculae, rostrum, eyes, antenniferous

tubercles and antennae excepting basal segment brown. Acetabula, a few spots on pleura, apex of ostiolar canal, reflexed posterior margin of metapleuron, and legs, except for pitchy brown femora, brown or lighter.

Size: male, length 2·72 mm., width (hemelytra) 1·33 mm.; female, length 3·16 to 3·33 mm., width (hemelytra) 1·55 to 1·66 mm.

Holotype, male (British Museum), Arthurs Pass, South Island, New Zealand, January, 1923, J. G. Myers. Allotype, female (H. G. Barber), and one female paratype, same data as holotype. The females are considerably paler, with more extensive ochraceous areas on the posterior lobe of the pronotum and on the coria and with the apices of the femora distinctly ochraceous.

Nysius huttoni Buchanan-White.

Nysius huttoni Buch.-White, *Ent. Month. Mag.*, 15: 33, 1879.

This species occurs on Lucerne, and is apparently very common in New Zealand. The eleven specimens before me are so variable in colour and even to some extent in structure that two species may be represented.

The dark form has the corial margins subparallel at base and then distinctly lamellately dilated. The corial disk is mottled with brownish throughout. The membrane is streaked with fuscous and white, giving a criss-cross effect when folded.

A male and a female of this form are at hand from the British Museum, determined by Buchanan-White and collected by J. J. Walker, New Zealand, October, 1901–November, 1902. 1910–384. A male from Ashburton (H. G. Barber Coll.) is faded, but apparently also belongs here.

Other dark specimens differ in that the membrane is marked with black basally, but is entirely clear apically.

Three males of this form were collected at Blenheim on March 13, 1921, on Lucerne (H. G. Barber Coll.), and one female was taken by J. G. Myers on December 13, 1921, at Whángarei.

The pale form has the corium entirely testaceous except for sinuate black markings at the apical margin. The costal margins are less dilated in some specimens. The membrane is clear or more or less cloudy posteriorly. The femora vary from a spotted piceous condition to uniform piceous except at apices.

A male from Whangarei and a male and female from Blenheim are from the same series as recorded above. An additional male is before me from Central Otago, January, 1921, " Linum " (H. G. Barber Coll.).

Rhypodes clavicornis (Fabr.)

Lygaeus clavicornis Fabricius, *Ent. Syst.*, 4: 169, 1794.

Coreus clavicornis Fabricius, *Syst. Rhyng.*, p. 201, 1803 (*non Coreus clavicornis* Fabricius, *Syst. Rhyng.*, p. 198 = *Coreus typhaecornis* Fabricius, *Syst. Rhyng.*, Emend.).

Nysius zealandicus Dallas, *List of Hemipt. Ins. Brit. Mus.*, 2: 552, 1852.

Nysius (Rhypodes) zealandicus, Stål, *Hemipt. Fabr.*, 1: 76, 1868.

Nysius clavicornis, Myers and China, *Ann. Mag. Nat. Hist.* (10), 1: 380, 1928.

Myersia clavicornis, Evans, *Bull. Ent. Res.*, 19: 353, 1929.

Rhypodes zealandicus, Evans, *Bull. Ent. Res.*, 20: 269, 1929.

An extremely variable species, some specimens of which have the sublateral lobes of the posterior margin of pronotum reduced or

wanting. Sexual differences are greater in this than in many Orsillini, the males being distinctly more slender and parallel-sided than the females. Forty-three specimens are at hand from various localities in both the North and South Islands. The specimens without pronotal lobes are mostly from South Island localities. A single female which is slightly flatter and lighter in colour, but no more so than a teneral specimen from eastern Lake Taupo, New Zealand, is labelled "Australia, Koebele," but this may very possibly prove to be an error. Dallas (1852) records one specimen as follows: "C. Van Dieman's Land. From Mr. Hooker's Collection."

A single male determined by W. L. Distant has been received from the British Museum from the collecting of J. J. Walker, October, 1901–November, 1902, 1910–384. Other material includes seventeen specimens in excellent condition sent to me by G. V. Hudson, Paekakariki, New Zealand, May 11, 1938; eight specimens without locality or date (H. G. Barber); and one or two specimens each from the following localities: Whangarei, December 13, 1923 (J. G. Myers); Korokoro, May 7, 1922 (T. Cockroft); Wellington, February 21, 1924 (E. Richardson), and two specimens, October 28, 1922 (J. G. Myers); Lyall B., D. M., January 13, 1922; Ohaupo; Mount Cook, January, 1909; Silverstream, January 14, 1922 (J. G. Myers); Motueka, December 30, 1920 (T. C.); Ashburton; E. L. Taupo, March 7, 1922 (E. H. Atkinson); two specimens, Arthurs Pass, 3000 ft., December 29, 1922, and one specimen, November 13, 1922 (J. G. Myers); Auckland, July 30, 1923 (O. H. Swezey); Wilton's Bush, Wellington, October 28, 1922 (J. G. Myers); two specimens, Otira, December 25, 1920 (T. C.).

Rhypodes sericatus Usinger, new species.

Moderately robust, with sides subparallel, about two-thirds as deep as greatest width and covered with a rather dense, short, silky-white, appressed pubescence throughout as well as some erect hairs on the head, pronotum and scutellum. Disks of head and pronotum very strongly, evenly, arcuately declivous.

Head about one-fourth broader, including eyes, than long, 24 :: 19; the anteocular portion longer than an eye, 8 :: 7; eyes relatively short and subrounded, scarcely more than one-third the width of interocular space; upper surface scarcely elevated along middle and densely clothed with appressed white hairs except for obliquely, anteriorly placed, subrounded, dull areas between ocelli and inner margins of eyes. Antenniferous tubercles prominent, but their outer angles scarcely or not at all produced. Bucculae prominent anteriorly, gradually reduced at level of antenniferous tubercles, the rostral groove not reaching base of head. Rostrum not reaching hind coxae, the first segment reaching well on to prosternum; proportion of segments one to four as 12 : 10 : 9 : 8. Antennae almost half again as long as greatest width of pronotum, 49 :: 34; proportion of segments one to four as 8 : 16 : 13 : 12. Pronotum about two-thirds broader than long, 34 :: 20; scarcely longer than head, 20 :: 19; and almost half again as broad as head, 34 :: 24. Disk moderately convex, the sides roundly depressed and with depressed areas sublaterally on posterior margin and a feeble impression behind callosities; finely

densely pubescent except for narrow sinuous callosities. Scutellum strongly triradiately elevated at middle, forming a rather sharp carina posteriorly. Hemelytra exceeding tip of abdomen by one-seventh the length of the membrane; membrane a little shorter than costal margin of corium and about as long beyond level of apices of coria as in front of this; clavus and corium covered with a short, fine, subappressed pubescence; vein R + M branching just beyond middle; Sc scarcely visible, costal area but little expanded, narrowly exposing connexivum, the costal margins feebly sinuate subbasally, then straight and parallel to slightly beyond level of apex of scutellum beyond which they gradually converge. Under surface distinctly pubescent except on coxal flanges, ostiolar and evaporating areas, and trichobothria bearing areas of abdomen. Posterior margin of metapleuron slightly concave, its lateral angle scarcely rounded.

Colour testaceous marked with fuscous and black above and tinged with ferrugineous beneath. Head black except for ochraceous along inner margins of eyes, apices of antenniferous tubercles and elevated portions of bucculae. Pronotum ochraceous to testaceous with dark fuscous punctures and black humeri (except very narrow margins) and region of callosities. Scutellum largely black with irregular pale areas between the punctures, particularly posteriorly. Clavus and corium testaceous with fuscous irregularly along inner margin and along commissure of clavus, irregular and faintly on vein Cu and irregularly but darkly along vein R + M and between this and costal margin except for broad, subapical, pale area. Apical margin of corium dark near apex and at joining of veins Cu and M. Membrane whitish with irregular fuscous spots, especially along middle. Narrowly exposed connexivum black with pale margins and sutures between segments. Under surface pale, with black sterna and black at middle of pleural disks and irregularly black-spotted abdomen basally at middle. Rostrum black on apical half. Antennae infuscated, dark brown to black with irregular ochraceous basally on first segment and at middle of second and apical three-fourths of third segments. Legs ochraceous with distinct black spots below and broad black areas above on femora and less distinct spots on tibiae and with apices of tibiae and tarsi infuscated.

Size: male, length 5·33 mm.; width (connexivum) 2 mm.

Holotype: male, Terawhiti, North Island, New Zealand, April 23, 1922, I. H. W. (H. G. Barber Coll.) and two paratypes: one, same data as type, and the other, on *Cassinia*, Terawhiti, April 23, 1933, I. H. W.

This species at first suggests an *Ortholomus* because of the feebly expanded costal margins, but, upon closer study, it is seen to have nothing to do with that Holarctic genus. Closest affinities are with other *Rhypodes*, from which it may be distinguished by its subparallel sides and subequal apical antennal segments.

Rhypodes myersi Usinger, new species.

Broad, subflattened, a little more than half as deep as greatest width at connexivum, 28::48, covered in great part with a moderately dense, subappressed, white pubescence and with erect hairs on pronotal and scutellar disks.

Head a little broader, including eyes, than long, 26::24; densely clothed with recumbent white hairs except for narrow, anteriorly divergent stripes from ocelli to inner anterior margins of eyes; outer angles of antenniferous tubercles slightly but distinctly, subacutely produced; bucculae strongly elevated anteriorly, abruptly and then gradually decreasing in height to level of anterior margins of eyes, the buccal groove continuing as a smooth black trough almost to posterior margin of head. Eyes small, not touching antero-lateral angles of pronotum, the head being a little exserted and the inner margins of the eyes rounded outward away from this point; width of an eye one-third the width of interocular space. Antennae short and thick; as long as head, pronotum, and half of scutellum; first segment very stout; second and third more slender, almost cylindrical; second segment almost as thick as front tibiae basally; fourth segment thickened and fusiform; proportion of segments one to four as 9:19:13:17. Rostrum slightly surpassing posterior coxae; first segment not quite reaching base of head; proportion of segments one to four as 16:16:17:13. Pronotum only slightly declivous; longer than head on median line, 26:21; three-eighths broader behind than long; one-half as wide at extreme anterior margin as at posterior margin, three-fourths as wide at level of callosities; lateral margins distinctly sinuate; posterior margin feebly, roundly, lamellately produced sublaterally; disk subflattened, irregularly covered with black punctures spaced from one to three puncture widths apart, except on slightly elevated callosities and humeri and along a median longitudinal line; callosities sinuate, bent anteriorly and then laterally on outer halves. Scutellum a little broader than long, 24::19. Hemelytra long, distinctly surpassing tip of abdomen, the membrane complete; lateral margins of corium slightly, evenly arcuate throughout their length, slightly exposing connexivum; claval suture with a very inconspicuous row of punctures on inner side near base; emboliar suture, seen from the side, also with some inconspicuous punctures; corium subhyaline; membrane rather clear, venation typical of *Nysius*. Ostiolar canal well developed, reaching to about middle of metapleuron, the apical lobe quite large, rounded and somewhat elevated; canal surrounded on metapleural and adjacent mesopleural regions by naked, dull, black areas. Posterior margin of metapleuron shining, produced as a broad lamella which is moderately reflexed; postero-lateral angles very broadly subrounded. Fourth visible abdominal segment, in the female, short but not concealed at middle, its posterior margin moderately angulately emarginate. Legs simple, the femora unarmed. Tibiae somewhat enlarged apically.

Colour black with ochraceous to whitish as follows: on apices of second and third antennal segments; pronotum excepting broad, black elevations at callosities, black discal punctures, and brown longitudinal lines either side of middle; median longitudinal line on scutellum except at extreme base; clavus except along commissure; corium except for faintly embrowned veins and dark brown vitta at middle of apical margin extending on to membrane; bucculae; anterior margin of prosternum and posterior margins of propleura;

folds of ostiolar canal but not apical lobe; lamellate posterior margins of metapleura; coxal flanges, inner parts of coxae, trochanters, variegated portions of femora between black spots, middle of tibiae, and bases of tarsi; narrow connexival margins above and beneath; and paired, sublateral glandular spots, two longitudinal vittae on middle of either side, and middle of segments behind third visible segment of abdomen beneath. Membrane a little clouded, subhyaline, with a distinct brown vitta at middle of base on either side becoming faint just beyond junction of interior veins but continuing obscurely to beyond middle of membrane.

Size: male, length 6·5 mm., width (connexivum) 2·3 mm.; female, length 7·5 mm., width (connexivum) 2·6 mm.

Holotype: female (H. G. Barber Coll.) Arthurs Pass, South Island, New Zealand, 3500 feet, December 22, 1922, J. G. Myers collector. Allotype, male (H. G. Barber Coll), and three female paratypes, same data as holotype. One male paratype, same locality as holotype, but taken on November 16, 1922. One male and one female paratype, Wakatipu, January 1, 1921, G. V. Hudson.

The specimens collected by Hudson are darker in colour with distinct, sublateral brown vittae on the pronotum, brownish veins and mottled areas on the clavus and corium, and black middle and hind femora with pale apices. The male collected at Arthurs Pass in November is considerably smaller than the other specimens, but otherwise typical.

Named in honour of Dr. J. G. Myers, the versatile Hemipterist, to whom we owe most of our New Zealand material in the Orsillini.

Myersi is not closely allied to any other Orsilline Lygaeid known to me. Its broad form, exserted head, and short bucculae are suggestive of *Nysius californicus*, a species with a more declivous pronotum, more slender antennae, shorter vestiture, basally dilated costal margins, and a shorter, medially concealed fourth ventral segment in the female. The true allies of *myersi* are doubtless to be found among New Zealand forms not yet discovered. Certainly it is abundantly distinct from any of the New Zealand species known to me at present. The subflattened form and flattened, laterally sinuate pronotum impart a superficially different facies to this species which tempts one to separate it generically. However, many allied forms may yet be found which may further elucidate its proper placement, so it is referred to the composite, primitive genus *Rhypodes* for the present.

Rhypodes chinai Usinger, new species.

Robust, moderately large, less than twice as broad across hemelytra as greatest depth at thorax, 35 :: 20; body surface polished, covered with a short, white pubescence which is rather dense and appressed except on posterior lobe of pronotum. Pronotal and scutellar disks with an additional vestiture of erect, fulvous hairs which are best seen from the side. Head and pronotum quite strongly declivous.

Head, including eyes, broader than long, 21 :: 18; interocular space a little more than twice as wide as an eye, 11 :: 5, with a small, polished, bare area in front of each ocellus; not strongly produced before the eyes, the distance from front margins of eyes to apex of

head subequal to distance to base of head from the same point; outer angles of antenniferous tubercles scarcely, roundly produced. Bucculae prominently elevated anteriorly, then abruptly decreasing in height to just behind level of antenniferous tubercles, not reaching base of head. Rostrum reaching to hind margins of posterior coxae, the proportion of segments one to four as 12:12:11:6. Antennae almost as long as head, pronotum, and scutellum together; slender, the second segment not as thick as front tibiae basally; proportion of segments one to four as 7:16:10:12; first segment except at narrowed base and middle of fusiform fourth segment about equally thick, second and third segments more slender. Pronotum as long as head on median line, a little narrower at extreme apex than long, 16::18; rather regularly widening posteriorly, the width at humeral angles a little less than twice anterior width, 29::16; lateral margins feebly, roundly swollen at level of callosities, a little sinuate behind this; posterior margin sublaterally depressed, faintly rugose, and feebly lamellately produced posteriorly over bases of clavi; disk a little convex, without lateral carinae, the rather dense punctures in irregular transverse rows less than one puncture width apart, the rows one or more puncture widths apart; feebly but distinctly depressed along posterior margins of naked, laterally sinuate callosities; a median, longitudinal, posteriorly irregular, impunctate line. Scutellum a little broader than long, 17::14, the "Y"-shaped elevation very prominent; sides carinately elevated; apex subacute. Hemelytra very long, the membrane exceeding tip of abdomen by more than one-third its length; clavus and corium opaque, superficially minutely punctured throughout, the claval and emboliar sutures without conspicuous rows of punctures; costal region with an extra vein on apical half very prominent, closely paralleling forked emboliar vein; costal margins subparallel for two-thirds the length of scutellum, then gradually roundly dilated, slightly converging posteriorly, completely covering the connexivum. Ostiolar canal extending over half the distance to lateral margin of metapleuron, the apical lobe prominent, raised, and rounded at apex. Posterior margin of metapleuron broadly reflexed, a little concave, the posterolateral angle not at all produced, rounded. Posterior margins of fourth and fifth abdominal segments below, in the female, deeply, angulately emarginate, concealed beneath third visible segment at middle.

Colour black with testaceous to white on the following: inner margins of eyes; pronotal disk longitudinally at middle, on anterior margin, and more or less on posterior half except for black humeral angles, black punctures, and broad longitudinal, ill-defined, fulvous fasciae either side of middle; apical median longitudinal elevation of scutellum; clavus except for a few scattered fuscous spots; corium except black apex and fuscous lateral margin on apical half and broad, transverse, subapical fuscous area; acetabula, trochanters, bases and apices of femora, middle of tibiae, and bases of tarsi; extreme apices of second and third antennal segments; and venter sublaterally on posterior half. Membrane pale and hyaline with more or less extensive fuscous between the veins, with a large, round,

black spot at base of membrane, another, more elongate and subtriangular, on either side opposite corial cell formed by forked emboliar vein.

Size: male, length 5·65 mm., width (hemelytra) 2 mm.; female, length 5·94 mm., width (hemelytra) 2·17 mm.

Holotype, male (British Museum) and five male paratypes, Mount Matthews, 3000 feet, September 25, 1921. Allotype, female (H. G. Barber Coll.) and one female paratype, Arthurs Pass, 3800 feet, December 26, 1922, J. G. Myers collector.

There is considerable colour variation in the paratypes, one male in particular, being much darker, almost entirely fuscous on the clavus and corium, the membrane generally infuscated, with white veins.

Perhaps closest to *myersi*, but entirely differently shaped, with more slender antennae, concealed middle of angulately emarginate fourth abdominal segment in the female, and different colour pattern.

Rhypodes stewartensis, Usinger, new species.

Very broad and robust, shining, and clothed with a short, appressed, white pubescence and with erect hairs, as well, on the pronotum and scutellum.

Head less than one-third broader than long, 23::18 1/2; anteocular portion longer than an eye, 8::6 1/2; eyes short and subrounded, about one-third the width of interocular space, 4 1/2::14; tylus very broad at apex and juga relatively well developed and slightly expanded at sides; antenniferous tubercles briefly but distinctly produced laterally. Upper surface densely clothed with appressed white hairs except for subrounded glabrous areas between ocelli and inner margins of eyes. Bucculae distinct anteriorly but very short, abruptly reduced at level of antenniferous tubercles, the rostral groove not reaching base of head. Rostrum reaching about to apices of middle coxae, the first segment extending well on to prosternum; proportion of segments one to three as 12:10:8 (last segment obscured). Antennae one-third longer than greatest width of pronotum, 47::36; proportion of segments one to four as 8:14:11:14. Pronotum moderately convex, being slightly elevated anteriorly, rounded at sides, and scarcely depressed sublaterally along posterior margin; sides broadly and feebly convex anteriorly at level of callosities, slightly sinuate behind this and broadly rounded at humeri, the humeral disk impunctate, clothed with appressed hairs particularly around callosities, and with sparser, much longer, erect hairs. Hemelytra scarcely exceeding tip of abdomen, the membrane distinctly shorter than costal margin of corium and about as long behind level of apices of coria as in front of this; corial veins, including Sc, distinct; vein R + M without a distinct inner branch, M. Costal margins feebly sinuate subbasally, then subparallel to level of apical third of scutellum beyond which they are moderately arcuate. Connexivum narrowly exposed. Under surface in great part pubescent. Posterior margin of metapleuron slightly concave, the lateral angle scarcely produced, subrounded. Female genital cleft very short, not reaching to middle of venter, the fourth ventral segment a little over half as long as third, and fifth a little less than half as long as fourth at middle.

Colour brownish to ochraceous marked with black. Head black with ochraceous along inner margins of eyes at apex of tylus and on elevated portions of bucculae. Pronotum ochraceous with black callosities and punctures and brown along posterior margin on either side of the middle, extending across humeri which have narrowly yellowish hind margins. Disk also dark brown at centre behind callosities. Scutellum almost entirely dark brown to black except for ochraceous apical carina. Clavus and corium ochraceous irregularly but generally covered with pitchy brown over a large portion of clavus and over corium except basally and subapically, the apical margin of corium dark brown to black apically and between inner angle and joining of vein Cu. Membrane clear hyaline except for distinct piceous area on either side at middle of apical margin of corium. Connexivum alternated, being black, with white at sutures of segments. Under-surface dark brown to black, with paler glabrous coxal flanges and with the venter variegated, especially posteriorly. Rostrum piceous, antennae black with the joints between segments somewhat paler and with the last segment brownish. Légs brownish, the coxae ochraceous apically. Femora black spotted beneath and entirely black above, with ochraceous apices, tibiae black subbasally and apically, and tarsi infuscated apically.

Size: male, length 5·05 mm., width (hemelytra) 2 mm.; female, length, 5·22 mm., width (hemelytra) 2·22 mm.

Holotype, female (British Museum), Stewart Island, 1926 (Harris) and allotype, male, same data, in my collection.

Perhaps closest to *chinai*, from which it differs in its more robust form, shorter rostrum, and shorter female genital cleft. The male is very much darker, but is not in perfect condition, so this may not be a natural situation.

A female is before me from Lyttelton, New Zealand, October, 1901, to November, 1902, J. J. Walker, and a male from Mount Cook, January, 1909, which are very close to *stewartensis*, differing only in the presence of a distinct branch of R + M. Whether these prove to be the same or a distinct species will depend upon further material in better condition.

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Fuchsite-bearing Schists from Dead Horse Creek, Lake Wakatipu Region, Western Otago.

By C. O. HUTTON.

[*Read before the Wellington Branch, Royal Society, October 10, 1940; received by the Editor, December 9, 1941; issued separately, June, 1942.*]

IN Dead Horse Creek (Glenorchy Survey District) a narrow band of fuchsite-bearing schists occurs interstratified with the normal quartzo-feldspathic types characteristic of the Chl. 4 subzone. These chromiferous rocks are on the line of strike of the Moke Creek lode of cupriferous pyrite and chalcopyrite, previously described by the writer (1934), but occur some 60–70 chains to the north. One of the fuchsite schists described in this paper was collected by McKay and described very briefly and somewhat inaccurately by Sollas (1906, p. 158). The occurrence of chrome-micas in considerable quantities in the Wakatipu region appears to be limited to this one occurrence in Dead Horse Creek, although during a recent trip to a tributary of Gill's Creek (northern boundary of Mid-Wakatipu S.D.) the writer observed vivid green spots of fuchsite in chlorite-muscovite schists.

Except for the presence of chromite-grains in dunite-serpentinite and harzburgite-serpentinite in the Springburn, a tributary of Gentle Annie Creek, Kawarau S.D. (Hutton, 1936), chromiferous minerals have not been found *in situ* in the country immediately east of Lake Wakatipu. Finlayson (1908) records the occurrence of a narrow dyke of serpentine, somewhat talcose, in Bushy Creek, 330 yards from its junction with the creek joining Lakes Kilpatrick and Moke. The present writer was unable to locate this serpentinite outcrop, even after very careful searching of the creek for its entire length. Nevertheless, in 1882, Cox reported the discovery of a boulder of chromite in the gravels of Moke Creek, and this would appear to strengthen the belief that serpentinites do occur in this region. However it must be pointed out that as some of the schists outcropping in Bushy Creek are highly chloritic and decidedly greasy to touch, an error may have been made in the identification of talcose serpentinites.

Composition and Properties of Fuchsite.

Fuchsite was separated from a fuchsite-oligoclase schist, first by crushing, then concentrating the mica on a cardboard tray, and finally centrifuging the concentrate in order to separate, in particular, pale green and colourless muscovite from the deep green fuchsite. The analysis made by Mr. F. T. Seelye is given in Table I, together with two analyses of fuchsite obtained from the literature; one of these analyses (column B) is of the original fuchsite from the Zillerthal Alps in the Tyrol.

TABLE I.

	A	B*	C
SiO_2	46.35	47.95	42.21
Al_2O_3	29.69	34.45	34.55
Cr_2O_3	4.60	3.95	2.03
Fe_2O_3	0.23	1.80	1.03 (with FeO)
FeO	0.85	—	
MgO	1.93	0.71	3.13
CaO	tr.	0.59	0.47
Na_2O	0.78	0.37	0.82
K_2O	10.53	10.75	9.16
H_2O+	4.69	—	6.77 (with H_2O-)
H_2O-	0.12	—	
TiO_2	0.28	—	—
P_2O_5	0.01	—	—
V_2O_3	tr.	—	—
S	0.05	—	—
MnO	0.01	—	tr.
BaO	0.15	—	—
F	0.04	0.36	—
	100.31	100.93	100.17

A. Dead Horse Creek, Glenorchy S.D. Anal.: F. T. Seelye.

B. Schwarzenstein, Zillerthal. Anal.: Schafhäutl, (Dana, 1904, p. 619).

C. Chrome pits, one mile west of Etchison Post Office, Montgomery County, U.S.A. Anal.: T. M. Chatard, (F. W. Clarke, 1890).

According to the X-ray work of Pauling (1930), who used fuchsite, and Jackson and West (1930, 1933), using muscovite, the structural formula for such micas may be expressed as $KAl_2(AlSi_3O_{10})(OHF)_2$; therefore the analysis of New Zealand fuchsite has been recalculated on this basis, that is of 12(O.OH.F) atoms to the unit cell (see Table 2).

TABLE II.

	wt. %	Metal Atoms		Metal Groups
SiO_2	46.35	3.125		4.00 (with 0.875)
Al_2O_3	29.69	2.356	0.875 / 1.481	
Cr_2O_3	4.60	0.245		
TiO_2	0.28	0.014		
Fe_2O_3	0.23	0.011		1.99 (1.481 to MgO)
FeO	0.85	0.047		
MgO	1.93	0.195		
Na_2O	0.78	0.101		
K_2O	10.53	0.906		1.01
BaO	0.15	0.003		
H_2O	4.69	2.108		2.10

Formula: $(OH)_{2.1}$ (Mg, Fe'', Fe''', Ti,Al,Cr)$_{1.99}$ [$(Si,Al)_4O_{10}$] $(K,Na,Ba)_{1.01}$

It will be observed that good agreement is obtained with the ideal formula. Considering the distribution of the metal atoms, just slightly over one-third of the Al ions are required to make up the Y group to the theoretical value of 4 demanded by the structural formula, while all the chromium, together with the remainder of the Al is required to bring the X group of cations of co-ordination

* There is a discrepancy between the analysis quoted by Dana (1904) and Bristow (1861, p. 145), in that the latter gives CaO = 0.42, and F = 0.35, with a summation of 100.75. The original publication, *Lieb. Ann.*, 44, 40, 1842, was not available to the present author.

number 6 to 1·99. Other points to note are the low percentage of Na_2O, the presence of a small amount of BaO, and the very low figure for fluorine.

In Table I the analyses of two examples of fuchsite have been included for the sake of comparison with the Wakatipu specimen. The close similarity of these three analyses will be seen, and it is of interest to note that the Wakatipu specimen contains the highest percentage of Cr_2O_3 yet found in fuchsite, with the possible exception of fuchsite from Outokumpu, Eastern Finland, described by Eskola (1933, p. 30). In this latter case the chrome-mica was separated from a fuchsite-bearing quartzite in an impure state, containing, in Eskola's estimation about 25% of quartz. The impure sample on analysis gave 3·68% of Cr_2O_3 or a possibility of 4·90% of Cr_2O_3 in the pure mineral, if the estimation of the amount of quartz was a correct one.

Scant data are available to the writer on the optical properties of fuchsite or of the chromiferous micas generally. At this point it might be stated that the optical values given for the mineral mariposite are incorporated, although discussion on the validity of this mineral species will be deferred till later in this paper. In Table 3 the optical properties of the Otago fuchsite and of some chromiferous micas are set out; it will be apparent that considerable variation exists between the different specimens, and this seems not to depend entirely on the Cr_2O_3 content. However, as stated above, there is at present so little information available that generalisation is not possible. A consideration of the data determined for A and B in Table 3 suggests that an increase in Cr_2O_3 causes an increase in refractive indices and birefringence, but a decrease in the size of the optic axial angle. The refractive indices found for a specimen of mariposite (Table 3, column F) would seem to be high, but these figures are substantiated by data determined by Knopf (1929, p. 38) for mariposite from the 2,170 foot level of the Melones Mine ($\alpha = 1{\cdot}58$, $\gamma = 1{\cdot}63$). Nevertheless Knopf (1929, p. 38) shows that there is considerable variation in the optical properties of different mariposites. The range of the optic axial angle for fuchsite is 30°–40°, while mariposite appears to be uniaxial or at the most to have an optic axial angle of only a few degrees. Hulin (1925, p. 25), observes that mariposite from Randsburg may have an optic axial angle of any value between 0° and 40°. (Further, he notes that the dispersion is very strong, with $r > v$).

The robin's-egg blue tint for the α vibration direction of the refractive index ellipsoid would appear to be a characteristic property of fuchsite, and in the case of the Dead Horse Creek specimen, this is the direction of maximum absorption. Winchell's absorption scheme (Table 3, column D) differs considerably from that determined for the New Zealand material, and unfortunately Larsen and Berman omit to record the relative strengths of the absorption tints. Finally, a distinct to very strong dispersion of the optic axes, with $r > v$ seems to be a characteristic feature.

TABLE III.

	A	B	C	D	E	F	G
% Cr_2O_3	4.60	0.27	2.03	—	—	—	—
Refractive Indices:							
α	1.5695±0.0005	1.5590	—	—	—	1.60	1.572
β	1.6040	1.5930	—	1.595	1.594	1.63	1.605
γ	1.6115	1.5973	—	—	—	1.63	1.607
$\gamma-\alpha$	0.0420	0.0383	—	as in muscovite	—	—	0.035
2V	37°±1°	40°	68° 16′ (2E)	68°–70° (2E)	40°	0°	30°–37°
Sign	negative	negative	—	negative	negative	negative	negative
Pleochroism:							
α	robin's egg blue	colourless	robin's egg blue	colourless to pale greenish-blue	robin's egg blue	—	greenish-blue
β	very pale yellowish-green	very palest yellow	yellowish-green	yellowish-green	yellowish-green	—	yellowish-green
γ	bluish-green	very palest yellow	bluish-chrome-green	dark bluish-green	chrome-green	—	bluish-green
Absorption:	$\alpha \geqslant \gamma > \beta$	$\gamma = \beta > \alpha$	—	$\gamma > \beta > \alpha$	—	Z < Y & X	—
Dispersion:	$r > v$ (strong)	nil	—	$r > v$ (distinct)	$r > v$ (strong)	—	$r > v$
Sp. Gr.	2.88	2.819	—	—	—	—	—

A. Dead Horse Creek, Glenorchy Survey District, Glenorchy Subdivision.

B. Chromiferous muscovite, Whitcombe Valley, Toaroha S.D., Mikonui Subdivision, Hutton, 1940.

C. Analysis No. 58, Dana's *System of Mineralogy*, 6 ed., pp. 617 and 619, 1904.

D. Properties of fuchsite, as stated by A. N. Winchell, pp. 269–270, 1933.

E. Properties of fuchsite, as stated by E. S. Larsen and H. Berman, p. 165, 1934.

F. Properties of mariposite, as stated by A. S. Eakle, pp. 197–198, 1923; some data from Larsen and Berman, 1934.

G. Properties of fuchsite. Velem, Koszeg Mts., given by E. Szadeczky-Kardoss, 1937.

Nomenclature of the Chrome-micas:

Considerable confusion appears to exist in the literature in regard to the terms mariposite, alurgite, and fuchsite, and it is pertinent to discuss this question now and to make some attempt to clarify the position. The term "fuchsite" was applied to a highly chromiferous mica from the Zillerthal Alps in 1845, and later Silliman, jun. (1868) described a new mineral for which he proposed the name mariposite, from the gold belt of the Sierra Nevada. The latter author mentioned positive qualitative tests for Fe, Ca, Mg, K, Cr, and Al, but published no optical properties or complete quantitative data. Later Hillebrand analysed two specimens of mariposite collected by Turner (1896), one of which was green and contained 0·18% Cr_2O_3, while the other was white and contained no Cr_2O_3. In regard to this white non-chromiferous mica, the writer must agree with Knopf (1929, p. 38) that it is not at all clear how such a mariposite is to be distinguished from sericite or muscovite. Mariposite has also been described by Hulin (1925, p. 25), but beyond stating that the mineral is green with an optic axial angle that may vary from 0° to 40°, no further data are given. In a paper on mariposite and alurgite, Schaller (1916) concludes that these two micas are identical, and later in a personal communication to Webb (1939, p. 127) Schaller states that "the names alurgite and mariposite may have some justification as varietal names, but certainly not as distinct species names."

Knopf (1929) in his study of the Mother Lode System of California, does not mention the term fuchsite, although he discusses mariposite at length. He states that the most conspicuous feature of this mica is its green colour, and some optical data are given. Finally Knopf defines the mineral mariposite as a green chromiferous sericite. Pabst (1938, p. 251) described fuchsite as an emerald-green chrome-muscovite while mariposite (*loc. cit.*, p. 252) is described as "a muscovite with a characteristic green colour due to the presence of chromic oxide." Murdock and Webb (1938, pp. 353-354) in some notes of Southern Californian minerals describe mariposite occurring in talc-sericite and talc-actinolite-schists and point out that the mica flakes are sometimes 10—12 mm. in diameter. Recently Webb (1939) has discussed mariposite in the light of Schaller's and Knopf's statements but there is little to add from this to the present discussion.

Unfortunately no exact optical or chemical data are available for mariposite and it seems clear that no definite ideas exist as to the exact properties of this mineral. Knopf (1929) states very clearly that the mica is a sericitic type, that is, if the present writer's interpretation is correct, the mica occurs in a very fine flaky form. But Murdock and Webb (1938), however, have used the term mariposite for a green chrome-mica occurring in flakes up to 10—12 mm. in diameter. Certainly such a coarsely crystalline mica is not sericitic in the generally accepted meaning of the term. In the European literature available to the writer the term mariposite has not been used for the description of green chrome-micas, whether in coarse plates or in a fine flaky form, but instead the term fuchsite appears

always to be employed. If the term mariposite is intended to imply green chromiferous potash micas, with a composition otherwise similar to that of muscovite, then it should be abandoned, for the term fuchsite has definite priority.

The question now arises as to the amount of Cr_2O_3 necessary in a mica to warrant the title of fuchsite, for the writer has shown (1940, p. 330B) that only a very small percentage of Cr_2O_3 will cause a very considerable green colouration of muscovite. However, as a result of the writer's investigations of these micas, an important content of chromium is necessary before the characteristic robin's egg blue tint is developed along the α vibration direction. Therefore it is suggested that

(1) the term mariposite be abandoned;

(2) potash micas with less than 1% of Cr_2O_3 be described as chromiferous muscovites and,

(3) micas with 1% or more of Cr_2O_3 be described as fuchsite.

Such examples (3) as have so far been described are characterised by the robin's egg blue tint for the α direction and by distinct or strong dispersion ($r > v$).

Redingtonite:

Occurring in specimen P. 1792 is a deep lilac or purple coloured earthy material that is intimately associated with folia of fuchsite. Microscopically it is usually granular, though rarely prismatic. The prismatic crystals have straight extinction and positive elongation. Refractive indices were determined as follows: $\alpha = 1{\cdot}475$ and $\gamma = 1{\cdot}485$; $\gamma - \alpha = 0{\cdot}010$. The optical character could not be determined owing to fine grain-size. Microchemical tests indicated that the substance is water-soluble and strong reactions were obtained for Cr, Fe''', (SO_4) and H_2O. Hence the mineral is believed to be a hydrated chromium sulphate with some ferric sulphate. The only recorded mineral with closely similar properties is redingtonite, a mineral described by Melville and Lindgren (1890) from the Redington Mine, Knoxville, California. The writer's mineral is, therefore, tentatively identified as redingtonite until sufficient material is available for a complete quantitative analysis.

Petrology:

Fuchsite, in the Lake Wakatipu district, is an important constituent of two distinct types of schists that are found interbedded with quartzo-feldspathic schists of the Chl. 4 subzone of Hutton and Turner (1936), viz., oligoclase-fuchsite schists (P. 1792) and fuchsite-chlorite-schists (P. 1793). Both of these rock types are closely associated with one another in Dead Horse Creek. In hand-specimen, the first group of rocks is strongly schistose and coarsely foliated, bands of fuchsite alternating with bands of plagioclase and minor quartz. Striated cubes of limonite pseudomorphous after pyrite occur up to 5 mm. in length.

P. 1792: A thin section of a fuchsite-rich folium from this schist was briefly described by Sollas (1906, p. 158) but more representative sections have now been cut and are described here. Quartz occurs in water-clear, xenoblastic grains, averaging $0{\cdot}15$ mm. in

diameter, with undulose extinction noticeable in some grains. The feldspar, an important constituent, occurs in grains of similar dimensions and shows some variation in composition from grain to grain, and also within the same grain. Universal stage measurements indicate a composition usually varying from $An_{19}-An_{27}$, that is medium to basic oligoclase. Zoning was measured in two examples and gave data as follows: inner zone An_{27}, outer narrow zone An_{31}; in a second crystal, inner zone An_{25}, outer narrow zone, An_{30}. The peripheral zones have, therefore, in some cases, a composition of acid andesine, while the nuclear or central zones may be as sodic as medium oligoclase. Twinning on the albite law was developed rarely. This feldspar is apparently the unidentified mineral mentioned by Sollas (1906, p. 158). Fuchsite occurs in strongly pleochroic plates, 0·8 – 3·0 mm. in diameter, that exhibit considerable bending and even some fracturing due to later shearing movements. Associated with this deep-green mica are plates of colourless or pale green mica, which have the usual properties of muscovite. Zoning of muscovite or fuchsite was not observed. Twinning of the fuchsite on the mica law with (001) as composition plane, is commonly developed but it is not clearly seen until one orients the plates on the universal stage for determination of the pleochroism. In such cases the tints for α and β, and α and γ show on opposite sides of the composition plane. Of the accessory minerals, chromite is important, occurring in strings of tiny, coffee-brown octahedra (text-fig. 1) and also rarely in rounded grains up to 0·5 mm. in diameter (text-fig. 2A). These strings of grains either lie along the cleavage planes of the fuchsite or else they wind sinuously along the junction of mica plates. Rutile occurs in slender needles or prismatic grains, usually lying within the cleavage planes of the mica. Dense aggregates of dust-like particles of magnetite, grains of pyrite and pyrrhotite, complete the mineral association. Redingtonite, owing to its solubility in water, was not observed in thin section.

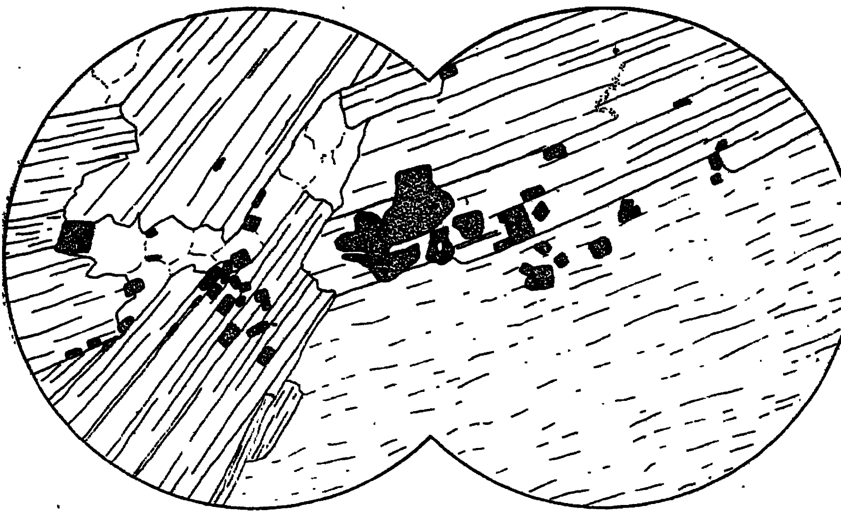

FIG. 1.—A fuchsite-oligoclase-schist (P. 1792) showing clusters of chromite grains in plates of mica; some oligoclase is also seen. × 110.

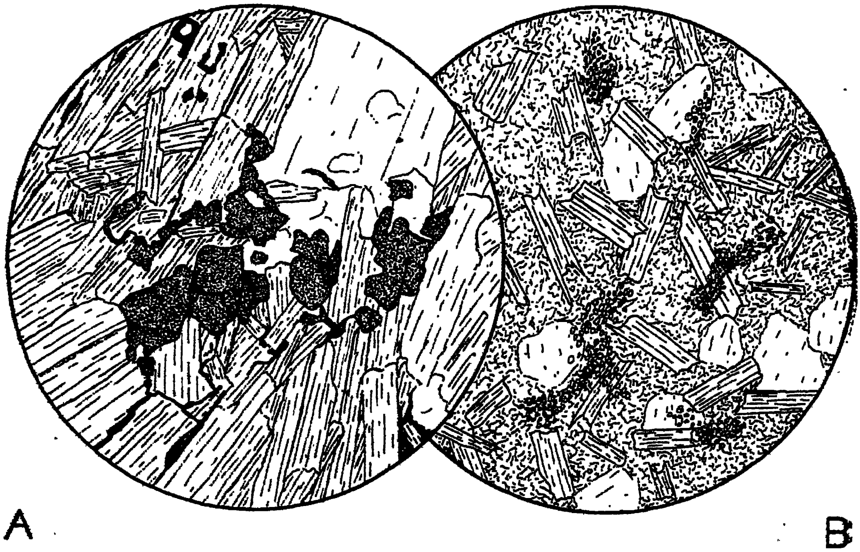

FIG. 2A.—Chromite and fuchsite in fuchsite-oligoclase-schist, P. 1792. Note the manner in which chromite has penetrated along the cleavage planes of the mica or along the boundaries between mica plates. × 26.

FIG. 2B.—A section of a fuchsite-chlorite-schist, P. 1793, cut parallel to *ab*, in order to show the unoriented habit of the mica, but strong alignment of prochlorite flakes. × 26.

P. 1793: Macroscopically this rock is also strongly schistose but only poorly foliated, the green mica being intimately associated with prochlorite and not segregated into well-defined folia. Fuchsite, with similar properties to that in P. 1792, occurs in plates that average 0·3 mm. in diameter. The orientation of this mica is discussed later. Titanite is an important minor constituent and is present in the form of spindle—or "insect-egg"—shaped grains, grouped into strings or dense clusters. Many of the grains are oriented with Bx_a approximately normal to the plane of schistosity. This feature has been observed before (Turner, 1936, p. 215; Hutton, 1940A, p. 52), and it has been suggested by the writer (1940A, p. 63) that it may be brought about in crystals showing an important development of an orthodome (102). The fuchsite and sphene are embedded in an almost isotropic base of a uniaxial, negative, chlorite with the following refractive indices: $\alpha = \beta = 1{\cdot}606$, $\gamma = 1{\cdot}610$, $\gamma - \alpha = 0{\cdot}004$. The chlorite is colourless with very faint dispersion and pale brown anomolous interference tints. These properties, according to the tables of Winchell (1936, p. 649), point to the mineral being a member of the prochlorite group or a variety with a composition lying just on the boundary separating the fields of rumpfite and prochlorite. The aluminous nature of the chlorite, however, is clearly seen in the analysis of this rock (Table 4, analysis B). Accessory constituents include pyrite, now partly limonitized, calcite ($\gamma = 1{\cdot}655$–$1{\cdot}660$), strings and clusters of clinozoisite or poorly ferriferous epidote, and tremolite in colourless acicular prisms. The amphi-

bole has the following optical properties: $\alpha = 1{\cdot}622$, $\gamma = 1{\cdot}640$, $\gamma - \alpha = 0{\cdot}018$; $Z \wedge c = 16° - 17°$, and it is optically negative; these properties would seem to indicate that the amphibole was non-aluminous and poor in iron.

The orientation of the mica has been studied in the three principal sections of the fabric: the poles of the (001) cleavage were measured for 100 flakes in each case.* The procedure adopted in this investigation is identical with that used by Turner and Hutton (1941, p. 231), but only the fabric diagrams of sections parallel to *ab* are reproduced here (fig. 3). From a careful study of all the diagrams it is concluded, on account of the fortuitous nature of the maxima, and absence of any girdle pattern,† that except for a faint tendency for some flakes to lie parallel to *S* in particular layers, the fuchsite fabric lacks preferred orientation. The slight tendency for orientation of the flakes parallel to the schistosity in narrow zones only, is clearly seen by rapid inspection of sections perpendicular to *a* or *b*. It should be noted that the maximum *Z* (fig. 3B)

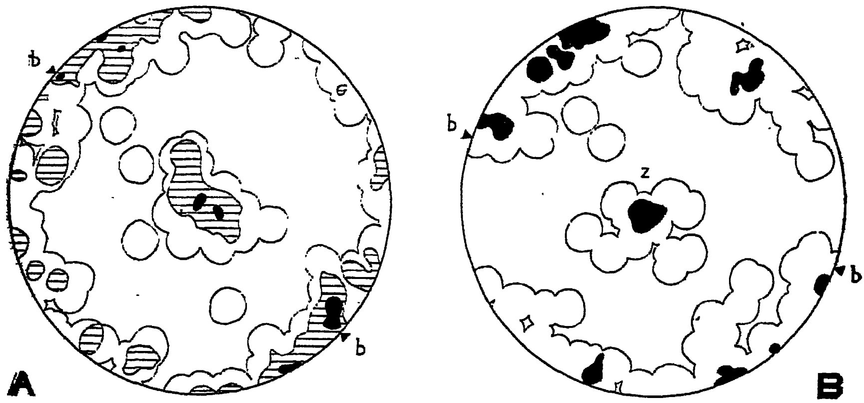

FIG. 3A.—P. 1793, a section approximately perpendicular to *c*. Fuchsite, poles of (001) in 100 flakes. Contours at 6, 3, and 1% per 1% area. The direction *bb* is that of the strings of sphene and epidote (probably = *b* of the megascopic fabric).

FIG. 3B.—P. 1793. The poles of (001) in 100 flakes of fuchsite in a section cut exactly perpendicular to *c*. Contours, 5 and 1% per 1% area. Direction *bb* is the trend of lines of sphene and epidote granules; this direction is parallel to a faintly developed *b* direction of the megascopic fabric.

represents flakes subparallel to *S*, but in all probability it should be spread outwards in all directions, since in any crystal subparallel to the section it is difficult to locate Bx_a (the normal to the cleavage) exactly. The prochlorite fabric, on the other hand, shows a strong

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* These sections are normal to the *a*, *b* and *c* fabric axes respectively, where *ab* is parallel to the schistosity (*s*), *b* is parallel to the lineation in *s*, and *c* is normal to *s*.

† The apparent girdles of Fig. 3 are due entirely to the tabular habit of the crystals measured. Equally strong apparent girdles appear in diagrams for sections normal to *a* or *b*.

parallelism of flakes with the schistosity and the strings of grains of epidote and sphene. The size of the platelets was, however, too small to allow any exact statistical estimate of the preferred orientation. The random orientation of the fuchsite is most readily observed in a section cut perpendicular to *c*, for here the high birefringence of the disarranged mica plates stands in marked contrast to the nearly isotropic base composed of basal flakes of prochlorite. Dr. F. J. Turner has checked the fabric diagrams and agrees with the above interpretation.

TABLE IV.

	A.	B.
SiO_2	56.03	40.16
Al_2O_3	25.64	23.29
Fe_2O_3	1.97	0.52
FeO	0.55	6.68
MgO	0.25	11.26
CaO	2.74	1.40
Na_2O	5.69	0.25
K_2O	3.47	6.04
H_2O+	1.46	7.44
H_2O-	0.48	0.20
CO_2	nt. fd.	tr.
P_2O_5	0.01	0.04
TiO_2	0.21	0.85
ZrO_2	nt. fd.	nt. fd.
S	1.30	0.05
SO_3	0.13	—
MnO	tr.	0.13
NiO	0.09	0.09
Cr_2O_3	0.21	1.61
V_2O_3	0.01	0.04
BaO	0.05	0.07
SrO	0.02	0.001
Cl	nt. fd.	nt. fd.
F	0.01	0.06
	100.32	100.18

A. Oligoclase-fuchsite-quartz-schist, P. 1792.

B. Fuchsite-prochlorite-schist, P. 1793.

The analysis of the oligoclase-fuchsite-quartz-schist is interesting in that a considerable percentage of CaO is shown and since apatite and sphene are only very minor constituents, most of the lime represents the anorthite molecule of the plagioclase; this supports the data obtained microscopically that the plagioclase may be as calcic as acid andesine. The SO_3 reported in this analysis is, Mr Seelye reports, that of the sulphate soluble in hot water, and this is considered to represent the acid radicle of the rare mineral redingtonite. Further the analyst reports that "on treating the sample with hot dilute HCl (1 HCl : 5 H_2O) in an atmosphere of CO_2, H_2S is evolved in amount equivalent to 0·57% of sulphur; this is probably derived from pyrrhotite." The presence of this not inconsiderable amount of pyrrhotite is important and, it will be suggested later, has some bearing on the origin of these rocks. The second analysis (Table 4, analysis B) clearly indicates the aluminous nature of the chlorite but it is also evident that the prochlorite is much more highly magnesian than those previously described (Hutton, 1940A, pp. 18–19)

from the schists of the Wakatipu area. It is possible that the chlorite may be chromiferous, but if so the Cr_2O_3 content will be low as there is no evidence of the tints characteristic of kammererite. In both analyses the presence of nickel is interesting, even although the quantities are low. There is no evidence of the part taken by nickel but the writer would suggest that it is possibly in the form of nickeliferous pyrrhotite.

Origin of the Fuchsite-bearing Schists.

Before discussing the origin of fuchsite in the Wakatipu rocks, it might be of value to consider very briefly the associations and origin of chrome-micas in other localities.

West Australia: Fuchsite has been very frequently described from this region, but it must suffice to give only a few of the better known instances. The mineral has been recorded as a constituent of schists of the Sherlock River in the Hammersley Range (Maitland, 1909), in quartz veins at Lennoxville (Jutson, 1914, p. 96), and in altered porphyries and porphyrites, of the Boulder Belt, Kalgoorlie (Stillwell, 1929). But the majority of the records describe this mica occurring in, or associated with, the altered and carbonated basic and ultrabasic rocks of the Kalgoorlie and Coolgardie areas *vide* Gibson, 1911, pp. 21–29; Simpson and Gibson, 1912, pp. 138–139; Farquharson, 1912A, pp. 79–80; Farquharson, 1912B (in Blatchford and Jutson); Farquharson, 1913 (in Feldtmann and Farquharson); and Thomson (1914, p. 636). Farquharson (1912A, p. 89; 1912B, pp. 94–95) is definitely of the opinion that the fuchsite-quartz-carbonate rocks have developed from very basic gabbros or peridotites by means of CO_2-bearing waters. In the south part of the Mount Margaret Goldfield, Clarke (1925, pp. 30 and 47) has described fuchsite-quartz-carbonate rocks that are closely associated with serpentinites and greenstones, and lenses of cupriferous pyrite (the Anaconda Copper Lode); it is Clarke's opinion (1925, p. 50) that the copper has originated from solutions emanating from the ultrabasic rocks, now represented as serpentinites, but states that there is no evidence of the origin of the fuchsite.

In America many accounts have been given of the association of chrome-micas with basic and ultrabasic rocks and Knopf's descriptions (1929, pp. 38–39) of the occurrence of "mariposite" in the rocks of the Mother Lode System is one of the most noteworthy. Knopf states that the fuchsite-ankerite rocks have resulted from hydrothermal alteration of serpentinites. In addition, Ferguson and Gannett (1932, pp. 47, 57, and 75) have described mariposite in quartz veins of the Alleghany District of northern California, and their field evidence leads them to conclude that the controlling factor in the distribution of the mica is the presence, or proximity, of serpentine.

In Europe Eskola (1933) and Lodnochnikow (1936) both describe fuchsite occurring in association with other secondary minerals, in altered ultrabasic intrusives, and these authors believe that the crystallization of the mica is the result of late solutions that brought about the serpentinization of the ultrabasic rocks.

In Rhodesia, Zeally (1915, p. 66) describes "green (?) talcose material," which Sampson (1931, p. 666) has determined as mariposite, occurring in association with large chromite bodies in talc schists. In the same region, Keep (1929, p. 66), Tyndale-Briscoe (1931, pp. 68–69), and Ferguson and Wilson (1937, pp. 30–32) record the occurrence of fuchsite in a variety of rocks, but in no case is the author clear as to the origin of the mica.

Fuchsite, containing an important amount of vanadium (0·48%), has been described by Chatterjee from quartzites in the Bhandara District, Central Provinces of India, but no statement is made as to the origin of the mica.

Therefore, in the majority of cases, when fuchsite is associated with ultrabasic rocks or their altered equivalents, the mica appears to have crystallized as a result of the action of solutions in some way associated with the late phases of ultrabasic intrusion.

In considering the problem of the rocks of Dead Horse Creek, any hypothesis that is advanced to explain their origin must take into account the following facts:

1. The great development of the chromiferous mica, fuchsite, and the not unimportant development of chromite and minor redingtonite.
2. The occurrence of a calcic plagioclase with reversed zoning in rocks of the chlorite zone.
3. The occurrence of pyrrhotite.
4. The presence of minor amounts of nickel, possibly as nickeliferous pyrrhotite.
5. The unoriented nature of the fuchsite but strongly oriented prochlorite in the fuchsite-prochlorite-schist.
6. The occurrence of muscovite or poorly chromiferous muscovite in schists containing fuchsite.
7. The occurrence of zones of schists in nearby localities, heavily impregnated with chalcopyrite, cupriferous pyrite, and nickeliferous pyrrhotite.

It is the writer's hypothesis that all these facts point to one conclusion, and that is that the fuchsite-schists are the result of chromium metasomatism brought about by the penetration and soaking of narrow zones of quartzo-feldspathic schists by solutions at high temperature, or aqueous chromium-bearing vapours, above the critical temperature of water, emanating from deep-seated intrusions of an ultrabasic nature; and further, that the chalcopyrite and nickeliferous pyrrhotite fahlbands have likewise originated from the same deep-seated source. Certainly the gangue minerals in the sulphide veins, quartz and sericite, are evidence that the sulphide emanations have penetrated a considerable distance from their source (Lindgren, 1933, p. 748). The occurrence of octahedra of chromite in nests and strings in one of the fuchsite schists excludes all possibility of this mineral being an original constituent of the sediments from which the schists have been derived, while the presence of pyrrhotite,

a sulphide so frequently genetically associated with basic and ultrabasic rocks, strengthens the hypothesis that the solutions originate from intrusions of an ultrabasic nature.

This hypothesis for the origin of chromite is not new but has been stressed by Sampson (1929, 1931), Ross (1929), Rynearson and Smith (1940), and Allen (1941). Sampson found that very considerable amounts of chromite may pass into the residual solutions of crystallizing basic or ultrabasic magmas and that these solutions are capable of very considerable migration. Further, Sokolov (1937, pp. 176–177) has pointed out that the rôle of water is very important for the formation of chromium ore bodies, and that the volatiles retain much of the chromium during the earlier stages of crystallization of an ultrabasic magma. In addition, Sokolov states that experimental work has shown that chromium is transported in water when the latter is above its critical temperature. If the chromite has its origin in this manner, it is reasonable to call upon a similar origin for the chrome-mica. It is believed that the chromiferous solutions reacted with any original muscovite in the original quartzo-feldspathic schists, resulting in a slight replacement of Al_2O_3 by Cr_2O_3 and subsequent formation of some of the fuchsite; the remainder of the mica is believed to have crystallized directly from the metasomatic fluids, the orientation of the mica plates bearing little or no relation to the existing schistosity. That the temperature at which this metasomatic replacement occurred was higher than that usually obtaining in the chlorite zone, is indicated by the calcic nature of the plagioclase and the reversed zoning displaced therein. In rocks of the chlorite zone the pressure-temperature conditions facilitate the development of an acid plagioclase, almost invariably albite with not more than 4% of the anorthite molecule (Hutton, 1940A, p. 63), but not until the oligoclase or garnet zone is reached does the anorthite content of the plagioclase begin to rise (Turner, 1933, pp. 244–246). In addition, the pyrrhotite must have been introduced into the schists by these hydrothermal solutions.*

As stated earlier, it is the writer's belief that the neighbouring chalcopyrite and pyrrhotite zones are genetically related to the chromium-bearing schists, and that they have been derived ultimately from the same source. This association of fuchsite, chromite, pyrrhotite and chalcopyrite is not dissimilar to that observed in the region of the Outokumpu copper mines in Eastern Finland (Eskola, 1933) and in the Anaconda district of Western Australia (Clarke, 1925). In order to explain the paragenesis at Outokumpu, Eskola advances the hypothesis that these minerals are in all probability hydrothermal in origin and are derived ultimately from the associated serpentinites.

No further evidence can be advanced at present as to the age of the basic and ultrabasic rocks and the genetically associated

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* Recently Turner (1942, p. 311) has noted the late introduction of nickeliferous pyrrhotite into the low-grade metamorphic rocks of Manuka Gorge, Otago; Turner finds that the pyrrhotite post-dates the formation of the quartzose veins.

chromiferous zones and sulphide veins of Western Otago, but Turner (1933, pp. 276–277) has suggested that the period of ultrabasic intrusion is possibly Lower Cretaceous; this date, it is the present writer's opinion, must still be accepted.

Acknowledgments.

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Geology of the West Coast of the Firth of Thames.

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INTRODUCTION.

THE district discussed in this paper comprises a well-defined area of 140 square miles lying between the Firth of Thames on the east and Wairoa River on the west. Its northern boundary lies along the estuary of Wairoa River and Hauraki Gulf and its southern limit is the range of hills that trends south-west from Kaiaua (New Brighton) on the west of the Firth of Thames.

The central portion of the area consists chiefly of heavily-wooded uplands, which rise in places to 2,000 ft. and more and on account of their rugged topography provide little opportunity for cultivation. In the lower parts of the region, however, river terraces are covered with rich soils and the staple industries are dairying and sheep-farming.

The chief township of the area is Clevedon, situated on Wairoa River, about 30 miles south-east of Auckland. The chief means of communication are the roads; for the railway is eight miles distant and Wairoa River is navigable only by very small craft.

Previous Work in the Area.

Owing to the difficulty of access and the poor roads, little work has been done on the geology of this district.

In 1864, von Hochstetter published a paper on the Geology of the Auckland Province, in which the present area was included. He described the oldest rocks, viz., the greywackes of this and adjoining areas, as of Silurian age, all other Palaeozoic and Mesozoic formations being absent. Overlying these basement rocks, he recognised two groups of Tertiary rocks, viz., the older Brown Coal formation and the Papakura Series which he correlated with the Waitemata Series of Auckland. Only small areas of the Papakura formation occur; the coal formation does not appear until the Lower Mangatawhiri Valley is reached in the south.

The district has been touched on in various reports by Hutton, Cox, Park, McKay and Fox, and in some detail by Bartrum (1927) and Mead (1930). The adjoining areas on the west and south have been described by Laws (1931), Healy (1935) and Lyons (1932) and their accounts illustrate the close similarity of the several districts.

STRATIGRAPHY.

The rocks of the district are separated into three distinct groups as follows:

(a) Greywackes of the Hokonui series (? Mesozoic)

(b) Waitemata sandstone (? Miocene)

(c) Post-Tertiary deposits.

(a) *Greywackes.*

The oldest and most abundant rocks outcropping over nearly three-quarters of the area described, are fine-to-medium-grained greywackes of uniform character and, with one possible exception, apparently unfossiliferous. Since they appear to be continuations of those on the flank of the great Mesozoic syncline that trends north-east from Kawhia, a Mesozoic age for these greywackes seems likely.

The fresh, unweathered rock is bluish-grey in colour, very hard, and breaks with a conchoidal fracture. Microscopically, the rock is composed of an even-grained mosaic of feldspar and quartz in subequal amounts with minor quantities of ferromagnesian minerals and occasional flakes of biotite and chlorite. Fragments of a fine-grained sandstone are found in the specimens from Otau, at the head of Ness Valley and nodules of chert up to an inch in diameter were observed in a sample from Kawakawa Bay.

Everywhere except along the sea-coast and the more youthful stream valleys, the greywacke is weathered to a stiff creamy or iron-stained residual clay, the kaolinisation of the feldspars being greatly facilitated by the closeness of jointing which characterises these rocks.

This regular spacing of joints produces cuboid blocks which soon give rise to spheroidally weathered cores that resemble boulders of Tertiary sandstone. In general, the jointing has destroyed all traces of the original bedding planes, but at Raukura Point, one mile north-east of Kawakawa Bay, there is a distinct trace of bedding with dips of 60 deg. west. The dominant greywacke is replaced locally by a slaty rock, as along the coast between Kawakawa Bay and Orere Point.

In a section of highly siliceous greywacke from a hogback near the headwaters of the Parataki Stream, below Plow's farm at Otau, the writer noted a cylindrical portion 1/30 in. in diameter with a roughly crenulated end and filled with feldspar. This suggests the replacement of an echinoid spine and if this interpretation is correct the specimen is the only record of fossil remains in the greywacke of the district.

(b) *Tertiary Beds of the Waitemata Group.*

Upon the basement of greywacke, probably Mesozoic in age, lie, with strong unconformity, Tertiary beds of small extent.

It is noteworthy that such beds as those of the Otamatea (Upper Cretaceous-Piripauan) and Onerahi (Mid-Eocene-Bortonian) formations, which are widespread in North Auckland, are absent from the present area, though fragments of the Onerahi limestone have been recognised by Healy (1935) in a volcanic deposit at Ramarama, 12 miles south-west of Clevedon.

The absence of these beds and of the Tertiary coal-measures which occur farther west in the Hunua district shows that there are very large gaps in the post-Hokonui succession.

Although, prior to the late Tertiary orogeny, the rocks of the Hokonui Series must have been covered with a considerable thickness of Tertiary strata, yet to-day only one small remnant survives on

the highland block. Beds of the Waitemata Series (in modern geological classification, this would be called a group—see "Classification—Nomenclature of Rock Units," *Bull. Amer. Assoc. Petr. Geol.*, vol. 23, no. 7, pp. 1068–1088), a term introduced by Hochstetter (1864) for "the horizontal beds of sandstone and marls which form the cliffs of the Waitemata Harbour," outcrop at Otau, at the head of the Ness Valley. Here, a moderately well-defined sequence of sandstones and calcareous grits underlie a portion of the uplifted remnant of a peneplain that lies west of Kohukohunui. The section is best seen along McKenzie Road, which passes westwards from the Ness Valley road at Trig Station 1946.

As with most of the neighbouring Tertiary localities, the sequence is far from complete, so that correlation is difficult.

Access to Otau from Clevedon is by way of the Kawakawa Bay road to Ness Valley. From the amphitheatre-like end of the valley, the road takes a sharp turn to the west and after a tortuous climb of some three miles reaches Otau at an elevation of about 1300 ft.

Greywacke is prominent in all the roadside cuttings up to the height of 1040 ft., where the hard older rock gives place to a soft tuffaceous sandstone containing pellets of halloysite approximately 0·2 in. in diameter. As the road continues to ascend, the sandstone becomes markedly finer.

Where the road gains the surface of the elevated peneplain, the turn-off to the west brings one into McKenzie Road, where an excellent vertical section of the undisturbed and approximately horizontal Tertiary cap is obtained.

Here are exposed about 300 ft. of tuffaceous sandstones and grits with occasional thin limestone beds; these become noticeably coarser and in places conglomeratic towards the base, which is seen in the headwaters of Cossey Creek. The whole is overlain by a fine-grained white calcareous sandstone in which the only fossils seen were an internal cast of *Turritella* sp., *Pecten williamsoni* Zittel and a few Foraminifera. A notable feature of the sandstones is the presence in them of masses of grey-green kaolin up to 9 in. across. The green sandstones and sandy limestones which contain abundant Foraminifera and Bryozoa consist chiefly of quartz and calcite. In addition glauconite, chlorite, muscovite, hornblende, augite, halloysite, and occasional crystals of magnetite were recognised.

Correlation and Palaeontology of the Beds.

The presence of intercalated tuffaceous sandstones and grits throughout the succession immediately suggests correlation with the "Parnell Grit" formation of the Waitemata group at Auckland. The sandstones and grits under discussion closely resemble the normal facies of the "Grit" in exhibiting spheroidal weathering and in containing a number of well-preserved remains of Bryozoa and small *Pectens*, but are distinctly finer.

In support of this correlation, there is also the evidence afforded by the presence of green sandstones in the section. In these latter are large numbers of Foraminifera, Bryozoa and small pelecypods.

The presence of this phase in company with the grits suggests correlation with the Turanga Greensand beds, which outcrop in numerous localities throughout the Whitford district north-west across the Wairoa estuary, and are believed by Firth (1930) to be a phase of the Parnell Grit.

Another small area of Tertiary rocks occurs in the vicinity of Trig. 646, Wairoa South, about two miles south of Clevedon at an elevation of about 700 ft. above sea-level. Between Clevedon and Hunua, the Tertiary beds are first encountered as approximately horizontal, reddish sandstones which lie unconformably on greywacke in a road-cutting at an elevation of 480 ft. and attain a thickness of about 160 ft. Half-a-mile from the summit they give place to soft white sandstones which have been widely disclosed in slips and on examination are found to be slightly calcareous beds with rare fossils.

Lower beds of the sequence are seen in the headwaters of the Taitaia, a small stream on the west, where the facies is a coarse sandstone with intercalated thin bands of impure limestone. The sandstone continues north-eastwards on the hills to within a quarter of a mile of Wairoa River and underlies swampy areas at the head of streams where the closely underlying greywacke has formed temporary base-levels. Small sink-holes are common in the white sandstone formation indicating that there are limestone beds beneath.

Turner and Bartrum (1929) suggested that the beds of the Waitemata group represent the deltaic deposits of a large stream or streams draining a land-mass north of the present Waitemata area. From the more or less complete absence of fossil marine remains in great thicknesses of the beds it is apparent that the bulk of the sediments were laid down rapidly in an extensive, shallow sea during a period of progressive submergence.

List of Foraminifera from Tertiary beds from Trig. Station 1946, E. of Hunua (identified by W. J. Parr).

Nos. 1–9 on slide from Locality 1, light green sandstone.

1. *Quinqueloculina* sp. aff. *lamarckiana* d'Orb.
2. Nodosarian indet.; possibly *Dentalina consobrina* d'Orb.
3. *Cassidulina subglobosa* Brady.
4. *Rotalia* sp. aff. *lessonii* d'Orb.
5. *Amphistegina* sp. aff. *lessonii* d'Orb.
6. *Globigerina bulloides* d'Orb.
7. *Globigerina* sp. aff. *inflata* d'Orb.
8. *Cibicides pseudoungerianus* (Cushman).
9. *Miogypsina* sp. aff. *irregularis* (Mich.).

Nos. 11–26 on slide from Loc. 2, dark-green sandstone.

11. *Glomospira charoides* (Jones and Parker).
12. *Textularia* sp.
13. *Quinqueloculina* sp. aff. *lamarckiana* d'Orb.
14. *Dentalina consobrina* d'Orb.
15. *Nonion* sp. aff. *novozelandicus* Cushman.

16. *Nonion stachei* Cushman (sp. just been described from the shell-bed, Target Gully, Oamaru).
17. *Elphidium advenum* (Cushman).
18. *Cassidulina subglobosa* Brady.
19. *Eponides umbonatus* (Reuss).
20. *Gyroidina soldanii* (d'Orb.).
21. *Rotalia* sp. nov. aff. *clathrata* Brady.
22. *Amphistegina* sp. aff. *lessonii* d'Orb.
23. *Globigerina bulloides* d'Orb.
24. *Globigerina* sp. aff. *inflata* d'Orb.
25. *Cibicides refulgens* Montfort.
26. *Miogypsina* sp. aff. *irregularis* (Mich.).

Parr remarks "The most important species is *Miogypsina* sp. aff. *irregularis*, which Chapman recorded from Pakaurangi and Hokianga South Head. It was also listed from the Maraetai-Whitford area in Mr. C. W. Firth's paper. A species which is new to the Waitemata beds is *Glomospira charoides*. You will notice also that a species of the Miliolidae, *Quinqueloculina* sp. aff. *lamarckiana* is present; the family has not been recorded previously from the Waitemata beds. I commented on this fact in my note on the Bombay forams."

(c) *Post-Tertiary Deposits.*

The Waitemata period of sedimentation was brought to a close by the Kaikoura orogeny (Cotton, 1916); and, following the subsequent extensive erosion, varied deposits of both sedimentary and volcanic materials accumulated in the present area.

The most outstanding accumulations of this type are the river terraces so conspicuous in the Clevedon and Orere districts. Their materials consist chiefly of greywacke boulders, pumiceous sands and silts, and occasional pebbles of andesite.

After the Kaikoura orogeny, the mid-Auckland area was subjected to prolonged erosion; and the land was reduced substantially to a peneplain which at present is a dissected upland. This was followed by long-continued uplift so that the strand-line was lowered relatively 600 ft. The uplift, however, was interrupted by several periods of standstill of sufficient duration to allow the streams to become graded with respect to current sea-level and to develop benches, still partially preserved at elevations of approximately 350 ft., 100 ft. to 120 ft., 40 ft. to 60 ft., and 15 ft. to 20 ft. above present sea-level (Turner and Bartrum, 1929).

A sharp uplift of the order of from 150 ft. to 200 ft., caused the re-invigorated streams to entrench themselves in narrow, gorge-like valleys in their flood-plains, where these had been carved or built. This was shortly followed by a widespread, probably eustatic movement of depression whereby the coastal lowlands were submerged and the characteristic embayed shorelines of many North Auckland harbours formed.

The only movement subsequent to this drowning has been an uplift of from 5 ft. to 8ft. in Recent times.

The most noticeable erosion level is that of the terraces 135 ft. above sea-level which adjoin Orere Stream and are related to the 150 ft. terraces on the Coromandel Coast opposite, as recorded by McKay (1897) and Fraser (1910). Their construction apparently commenced when movement along the bounding faults of the Hauraki depression had caused the uprise of the land-mass west of the present Firth of Thames relative to that now submerged beneath this latter embayment (Bartrum, 1927). Fractures seem to have developed earliest in the north and to have crept slowly south, whilst the extent of movement has been greater on the north than in the south, so that, as pointed out by Cotton (1916), the northern end of Coromandel Peninsula shows a coastline of submergence which contrasts strikingly with the fault-coast farther south.

As the land rose, the invigorated streams spread their alluvial fans of gravels at the foot of the growing fault-scarp, and later consolidation has given them the compaction that they now exhibit in the lower conglomerate in the Orere Valley. Shortly, however, cessation in the supply of fan gravels was occasioned by a somewhat spasmodic, slow, general submergence accompanied by temporary interruption in the differential movement of the adjacent blocks.

As the trough of the graben subsided, the sea crept slowly southwards; and the occurrence of a sea-beach, a few feet above swamp level at Maukoro, 18 miles south of the present shore of the Firth of Thames, indicates that the former shore-line was many miles farther south than now. (See Bartrum, 1927.)

There is no doubt that the sea would have extended much farther south, but for the fact that the ancient Waikato River then followed a northerly course through Hinuera Valley (Cussen, 1893) into the valleys of the present Piako and Waihou Rivers and thence into the Firth of Thames. Here in sheltered waters the fan gravels were replaced by delta deposits.

The materials of this phase of deposition were chiefly pumice silts brought by the river from the great central rhyolite plateau near Taupo. At Orere Point, these silts and accompanying mudstones represent the top-set beds of such a delta which increased in thickness as sea-level gradually rose.

During its passage northwards, the river left in its train deposits that are now represented by remnants of fairly well consolidated beds of pumice and other debris west of the railway at Walton and Waharoa which must be correlated with those at Orere (see Bartrum, 1927, p. 251).

Progressive sinking of the region ultimately allowed a thickness of material well over 1200 ft. to accumulate, as proved by well-bores near the above-mentioned places.

Marked changes in the process of filling the graben are shown throughout its length. At Clevedon, Mataitai and southwards from Orere Point are terraces constructed of pumice which reaches an elevation of not less than 100 ft. above sea-level in the highest of these benches. Many of them are small, however, and the most constant terrace is one about 35 ft. to 40 ft. above sea-level.

Greywacke pebbles in layers interbedded with the pumice of the terraces are so badly decomposed as to indicate that the terraces represent relics of an early filling of the graben far more extensive than that of to-day and deposited when the land was probably considerably lower with respect to sea-level than now.

An uplift of at least 150 ft. followed this period of extensive sedimentation and in consequence the Waikato River is believed by Bartrum (1927) to have excavated a wide trough, removing the northern portion of its earlier delta and leaving as relics of it only the fringe of terrace pumice that now exists along the western shore of the Firth.

Considerable depression, indicated to-day in the topography of the North Auckland harbours, followed; and Henderson and Grange (1927) show that at about this period the Waikato appears to have become so overburdened with waste that it was forced to aggrade its bed and spill over from its course through Hinuera Valley into a new route through Mangatautari to Cambridge, whence it followed approximately its present course along the earlier valley of the Waipa.

Bartrum (*op. cit.*) here suggests that in conformity with the course of events at Auckland, the beds of pumiceous debris were removed in large part by the work of rejuvenated rivers following an uplift which raised them considerably above their present position.

This brings us now into comparatively Recent times; and here we must consider the terraces of the Wairoa, Orere, and neighbouring streams.

A. *Terraces of the Wairoa River near Clevedon Township.*

Probably as a result of slight Recent uplift the Wairoa River is entrenching itself in a small flood-plain carved in resistant greywacke a few feet above stream-level near Clevedon township. In the neighbourhood, more especially alongside the road to Kawakawa Bay two flights of prominent terraces occur with such marked regularity of surface as to suggest genetic relations to earlier sea-level.

The lower terrace stands about 35 ft. and the upper about 50 ft. above sea-level. The former is particularly prominent on the west side of the river, whence it continues northward and also extends as a considerable flat in the Clevedon-Papakura valley. It is not prominent, however, east of Wairoa River although perhaps represented in extensive terraces of about equal elevation a little north of Kaiaua (New Brighton). The main terrace on the eastern bank of the river is the upper one that is about 50 ft. in elevation above sea-level.

Distinct small remnants of the higher terraces occur at Kawakawa Bay, east of Clevedon. A succession of small terraces, the lowest of beach gravels, and only a few feet above storm-beach level, and the highest about 30 ft. above sea-level, are eroded in the delta gravels of a small stream entering the bay.

Professor Bartrum informed the writer recently that he had discovered a beach terrace of fine greywacke pebbles reaching up to

80 ft. above sea-level about half-a-mile north of Kawakawa Bay. This sets a very definite limit to the north edge of the pumiceous deposits laid down in the Firth of Thames.

B. *Terraces of Orere Stream and of the Adjacent West Coast of the Firth of Thames.*

Seawards from its confluence with Paratahi Stream, Orere River has in its valley several prominent flights of terraces, one of the most persistent being a gravel-built bench 30 ft. above the level of the entrenched, swiftly-flowing stream.

A few cuspate remnants of terraces stand out at various intervals above this bench; and in the neighbourhood of Orere School, about 3½ miles from the sea, an extensive ancient plain begins approximately 135 ft. above sea-level at the mouth of the stream, rises gently inland, and spreads out in delta fashion seawards.

At the base there is a strongly-cemented coarse conglomerate made up of considerably weathered pebbles of greywacke averaging from 2 in. to 3 in. in diameter. The shape of the pebbles indicates that they are alluvial in origin; and the inference that they were laid down in an alluvial fan is confirmed by the intercalated, thin, discontinuous beds of mudstone or shale, with some layers rich in altered vegetation. In places, small trees in the position of growth are encountered.

In several small sections, both north and south of Orere Stream, bands of deep blue clay are conspicuous and, at a corresponding level, there occur in the lower conglomerate about half-a-mile south of Orere Stream, concretionary spherules of vivianite that has crystallised in radial fibres.

The 35 ft. terraces noted above near Clevedon have their counterparts in the valley at the mouth of the Tapapakanga Stream, approximately 1½ miles south-east of Orere Stream. The terraces are incised in a relatively compact silt overlain by a thin cap of stream-gravels in the shape of an alluvial fan.

Igneous Rocks.

The only igneous rocks known from the district are andesites and basalt of small extent. Basalts are absent from the main elevated block, but west of it have erupted in at least three places along the line of the Wairoa fault and are widespread farther west.

1. *Otau and Uplands at the Head of Ness Valley.*

Scattered over the elevated peneplain and neighbouring ridges at Otau, south-east of Clevedon township, are numerous boulders of volcanic rock intermingled with boulders of greywacke that rest on the cap of Tertiary sediments. No outcrops were seen in place; but the deep red colour of the soil suggests the presence of a large igneous mass intruded into the greywacke. The boulders are found fresh as well as deeply weathered and form groups in scattered areas over the whole peneplain. Pebbles of similar andesites occur among the deposits of Aro Aro Stream.

In hand specimen, the rock is a hard, dark, coarsely porphyritic andesite, the phenocrysts being chiefly feldspar and ranging in size up to ⅛ in. in length.

Microscopically, the rock is a strongly porphyritic hyalopilitic pyroxene andesite with extremely abundant, strongly zoned plagioclase approximating to basic labradorite. The pyroxene is chiefly a strongly pleochroic hypersthene, though occasional large crystals of pale green augite also occur. The groundmass is microlitic, in some rocks being hyalopilitic and in others pilotaxitic. Accessory minerals are sphene and apatite.

An analysis made by Mr. F. T. Seelye, of the Dominion Laboratory, through the kindness of Dr. J. Henderson, Director of the Geological Survey, proves the rock to be a normal andesite with dacitic affinities. It is interesting to note that the norm shows 17·38 per cent. of free quartz, though the microscopic examination failed to reveal any. Most of it, however, is probably distributed through the glassy base.

ANALYSIS B3150—Hypersthene andesite from Trig. 1946, Otau.

	%
SiO_2	59.67
Al_2O_3	17.10
Fe_2O_3	2.42
FeO	3.46
MgO	3.32
CaO	6.25
Na_2O	3.29
K_2O	1.05
$H_2O < 105°$ C.	1.24
$H_2O > 105°$ C.	0.97
CO_2	0.02
TiO_2	0.79
ZrO_2	nt. fd.
P_2O_5	0.15
S	tr.
Cr_2O_3	nt. fd.
MnO	0.12
BaO	0.04
SrO	tr.
NiO	tr.
	99.89

NORM.

Q.	17.38
Or.	6.23
Ab.	27.84
An.	28.79
Di.	0.96
Hy.	11.07
Mt.	3.52
Il.	1.51
Ap.	0.37

"II.4.3(4).4" Tonalose.

2. *Kawakawa Bay.*

Along the foreshore below the point at which the road from Clevedon descends into Kawakawa Bay, a line of some 20 or 30 large boulders, 3 ft. and more across, runs north-west for approximately 100 yards. The rock is similar to that of the boulders near Otau, but differs slightly in the greater proportion of hypersthene to augite, and these ferromagnesian minerals are now markedly more abundant.

In respect of age, these andesites may, with confidence, be correlated with similar rocks forming prominent terrains at Whangarei Heads, North Auckland, and Coromandel Peninsula. In the last area, the andesites belong to what is termed the Beeson's Island Series, regarded as of Miocene age; and it appears safe to correlate the present rocks with this series, especially as both occurrences are closely related petrologically and occur in similar country.

3. *Hunua Falls.*

The only other known igneous rocks in the district occur at Hunua Falls and Paparimu on the Wairoa River, the latter forming the boundary line between the Clevedon area and the block farther west. The rocks at both localities are Pleistocene basaltic flows and were described in detail by Healy (1935), who stated that they are porphyritic and vesicular basalts rich in olivine. At Hunua Falls, the rocks form a crater, over the southern lip of which the waters of Wairoa River tumble about 70 ft. Boulders of vesicular basalt are common throughout the river gravels between this locality and Wairoa South.

Physiography.

The district represents the most easterly of a series of earth-blocks which are bounded by major fractures trending north-north-west. This block, which is the most elevated of all, is divided into two, and consists of uplands rising to as much as 2,200 ft. east of the Kohukohunui fault.

An interesting feature of the block, in common with neighbouring blocks, is the notable absence of folding or flexure; the Tertiary beds wherever visible are only very gently inclined. It is thus evident that faulting unaccompanied by folding was responsible for the movement of the blocks. The disturbances apparently took the form of normal block-faulting accompanied by subsidiary tilting, the latter continuing after major movements along the fractures had ceased.

In 1929, Henderson envisaged the North Auckland Peninsula as a large arcuate block, broken up into many fragments, but with a pronounced south-westerly slope, the Firth of Thames and the Hauraki Plains being regarded as a foundered crest of the south-eastern extension of the main crustal arch, of which the uplands of the present area form a part, the arch having been forced upwards by lateral pressure.

Description of Faults.

(1) *The Miranda Fault-Complex.*

The steep scarp of this fault may be followed southwards along the coast of the Firth of Thames, and is continued by the hill margin on the western side of the extensive plains that partially fill the Hauraki Graben. Henderson and Bartrum (1913) were unable to find any direct evidence of the fault in this southern continuation; but they stated that " if a line be drawn tangent to the eastern tips of the spurs of the Hangawera Hills, its extension northward will trace the boundary between the Paturoa Range and the plain and gulf further north." It is possible, however, that in the south the fracture has given place to a monoclinal flexure such as Bartrum (1930) believes forms the extension of the Thames Fault-Complex on the east side of the graben.

The occurrence of hot springs at Miranda is evidence supporting the conclusion that the Hauraki depression is bounded by a fault on the west side, just as on the east by the well-demonstrated Thames Fault-Complex.

(2) *Lower Wairoa Fault.*

The presence of this fault was inferred by Firth (1930), although no direct evidence of movement was given. According to him, the abrupt slope that separates the bush-clad Maraetai Hills from the alluvial flat across which the Wairoa River meanders for two miles north of Clevedon, undoubtedly represents a maturely-dissected fault-line scarp. Bartrum (1937) mapped this fracture as a curved continuation of the north-east striking Papakura Valley Fault of Laws (1931).

Although this fault-line scarp bears away to the north, it is possible that a sub-parallel fault—a continuation of the Papakura Valley Fault—bounds the south side of Wairoa Estuary, where a similar clear differentiation with occasional shatter belts is shown.

(3) *Wairoa Fault.*

This very prominent fracture, first described by Laws (1931) determines the course along which Wairoa River makes its way north from Paparimu to Clevedon. Bartrum (1927) mentioned that the fracture extends north to the shore of Waiheke channel in Hauraki Gulf; and Firth (1930) has described details of its scarp. An extension farther north would intersect Motutapu Island along the contact between the Waitemata sandstones and the Mesozoic greywacke (Mead, 1930).

At the junction of Cossey Creek and Wairoa River, just north of Hunua Falls, an excellent section of the fault is displayed. The plane of the fault is approximately vertical; and the Tertiary beds show prominent drag-folding. A shatter-belt nearly 10 ft. wide occurs along the fault-plane and consists chiefly of slickensided material (Healy, 1935). This fault-section, however, is of little value in computing the relative throw of the opposing blocks along the fault, as the beds involved cannot be matched on both sides.

It is evident from the paucity of Tertiary beds both on the uplands east of the fracture and on the Hunua Depression immediately to the west, that erosion has played a prominent part in determining the present appearance of the scarp, which is probably a resequent fault-line scarp, or "fault-line erosion scarp" (Johnson, 1929). This fact makes it difficult to estimate the actual throw of the fault, but since areas on opposite sides of the fault have summit levels strongly suggesting that they represent a resurrected late mature or possibly peneplained surface, it is permissible to use their difference in height for calculating the relative movement.

Using this assumption, Healy (1935) computed a downthrow to the west of approximately 600 ft. near Hunua, and Laws (1931) estimated the movement a little further north as of the order of 400 ft.

(4) *Mangatangi Fault.*

The upland block which forms the major portion of the district is bounded sharply in the south by a fracture which trends approximately north-east and produces a steep descent to the Pokeno-New Brighton lowland along which the Mangatangi and Mangatawhiri Rivers have their courses. These streams have cut deep gorges in the

elevated block and on reaching the lowland have extensively aggraded their courses with the formation of prominent terraces (Lyons, 1932).

The throw, as computed by Lyons, is of the order of 600 ft. In the fault angle is a small area of Tertiary sandstones and brown coal of poor quality, the coal having been worked both here and more extensively at Kopuku some miles distant where the Bridgewater Colliery was opened before 1877.

Further indications of faulting are mentioned by Lyons (*op. cit.*), who noted the presence of slickensides in a tributary of the Mangatawhiri River and the steep abutment of Tertiary beds and coals against the scarp.

This fault is believed by Bartrum (see Lyons, *op. cit.*) to unite with the Waikato Fault of Gilbert (1921); and in a recent map, Bartrum (1937) showed the Mangatangi Fault as part of the same fracture-system as the Pokeno Fault of Bartrum and Branch (1936) and the Waikato Fault.

(5) *Other Faults.*

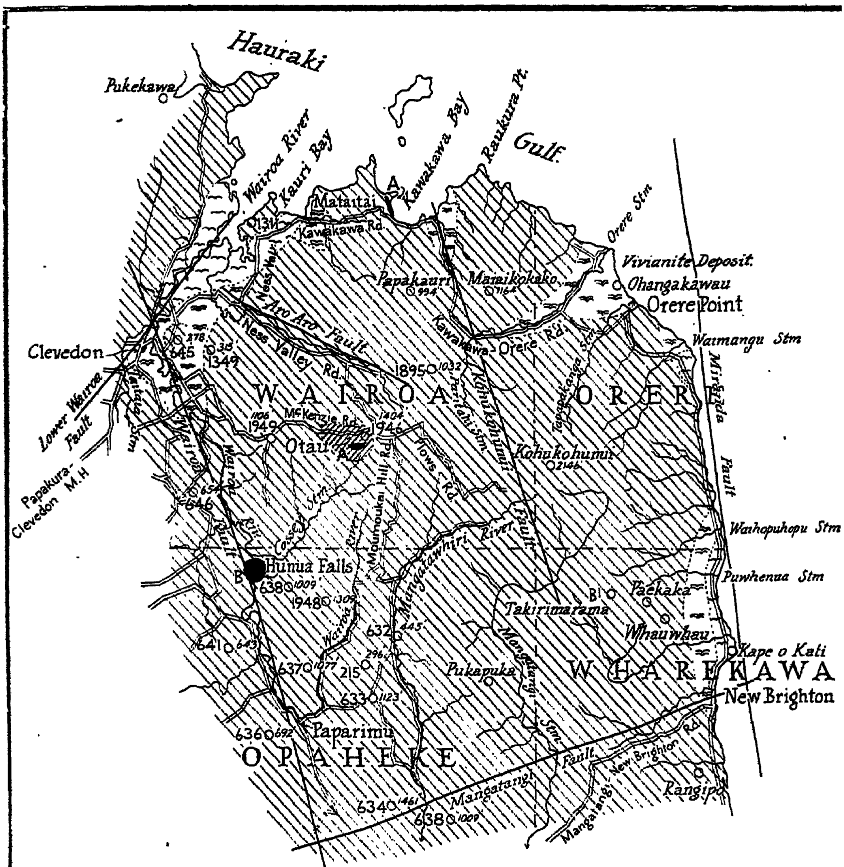
Curious topographical features in two areas within the district seem to indicate faulting.

The first is in the upland block at the head of Ness Valley at Otau. Here, an uplifted remnant of a peneplain about a mile and a-half square is bounded sharply on the east by a meridional, sharp-backed ridge about three miles long, which includes Kohukohunui or Mount London (2146 ft.). The discordance in summit level between this ridge and the undulating tableland to the west is about 800 ft. and from distant vantage points such as Waiheke and Motuihi Islands is striking. Between the two blocks, the headwaters of Paratahi Stream, a tributary of Orere Stream and the Mangatawhiri River are eroding in opposite directions.

Two hypotheses are possible to account for this feature. First, faulting may be supposed; the presence of a fault along the line that separates Kohukohunui ridge from the lower plateau west of it would account not only for the wall-like appearance of the ridge, but also for the straight courses of the streams entrenched along that line, and, in the case of the Paratahi, the remarkable right-angle bend that it makes on reaching the Orere Valley. On the other hand, the eastern block, composed wholly of greywacke, may merely represent a monadnock left during the peneplanation of the remainder of the block (Mead, 1930).

The second region that exhibits abnormal topographic features is the Ness Valley itself. This valley is remarkable on account of its marked asymmetry which impresses itself on the observer as soon as he enters the valley from the Clevedon end of the road that follows the valley.

On the north-east side, the Aro Aro Stream follows closely at the base of steep, almost rectilinear, slopes towards which incline long, gentle, dissected slopes from the other side of the valley. Near the floor of the valley, the slopes are composed of Pleistocene and Recent river gravels and silts.



Geological Map of
Orere and parts Wairoa, Opaheke, Wharekawa
Survey Districts.

— Scale —

4 3 2 1 0 4 8 Miles

Geology by D. Brown.

Reference

Sedimentary Rocks.

Recent	*Alluvium, Swamp & Beach deposits, Raised beaches*	
Pleistocene	*Terrace gravels, Consolidated sands*	
Miocene (?)	Papakura Series. *Sandstones, Calcareous grits, Impure limestones*	
Trias-Jura (?)	Hokonui Series. *Greywackes*	

Igneous Rocks

Recent to Pleistocene.	*Andesites*	A
	Basalts	B

The most likely explanation, to account for the straightness of the stream and the asymmetry of the valley, is the presence of a small north-west trending fault. Consideration has, however, to be given to the probability that an abundant supply of waste brought by streamlets from the south-western greywacke slopes may have pushed the stream against the north-eastern wall. This does not explain, however, the asymmetry and straightness of the valley. It is indeed probable that there has been some effect as a result of the process mentioned, but it could merely be consequential on the earlier results of faulting.

The Drainage of the Area.

The upland block is drained by three systems of streams, viz. (a) the short, swift streams draining east down the scarp of the Miranda Fault System; (b) the larger, slower streams draining the western portion of the area; and (c) those draining the northern parts of the region.

The Tapapakanga, Waimangu, Waihopuhopu and Puwhenua Streams are the main members of the first system, and none exceeds three miles in length. All are consequent and characteristically have built considerable alluvial fans of large boulders of greywacke. In their upper portions, they are deeply incised in the greywacke, and have produced close-textured topography with deep gullies separated by steep, narrow divides.

The second group comprises four main streams, divisible into two sub-groups.

The first includes the two largest streams of the area, viz., the Mangatangi and Mangatawhiri, which flow south-west over the greater part of the block. They commence as rivulets in deep gullies and, in a few miles, become graded streams with built-up extensive flood-plains; at still lower parts of their courses they enter steep, narrow gorges through which they are almost but not quite graded, having, particularly near the upper ends of the gorges, minor falls and rapids.

The extensive aggradation of the Mangatangi and Mangatawhiri Valleys above their gorges is evidently a result of reversal of earlier gradient caused, in the main, by slow, progressive, northward tilting of the block during its uplift, a movement which has given rise to several other curious features in the drainage system.

The headwaters of the Mangatangi are particularly interesting in this way. They drain eastwards from Kohukohunui towards the coast, later turning to the south-west in common with the other streams of the area.

Orere Stream, a member of the third group, the upper reaches of which drain the western slopes of Kohukohunui, after entering a widely open hollow at lower levels, bends sharply and escapes through a narrow gorge to the east coast.

The cause of these abrupt deviations of drainage is not quite clear, but, in the main, may be more or less satisfactorily explained by the above-mentioned tilting movement of the block and the formation of consequent streams as postulated by Bartrum (1927). This tilting is further borne out by the general lower summit levels from the south northwards, with the exception of Kohukohunui.

From a study of the map, it is evident that the Mangatangi River is in danger of becoming beheaded by the small swift streams that head inland on the eastern scarp. Appearances suggest, however, that the headwaters of the Mangatangi may represent an original east-flowing stream captured by a vigorous, consequent stream flowing to the south-west on the back-slope of the tilted block during its uplift.

This river and its western companion, the Mangatawhiri, flow south-west in deep gorges until they reach the lowlands beyond the bounding faults and finally join the Waikato River.

The second subgroup includes two smaller stream systems, viz. Upper Wairoa River and Cossey Creek, which, like the members of the first subgroup, also drain south-west. They differ from the above, however, in that they have not attained grade, so that they lack the wide open valleys and extensive flood-plains of the Mangatangi and Mangatawhiri.

The final group of streams includes the Lower Wairoa, Orere, Aro Aro, etc. These streams drain the north and north-eastern part of the district and exhibit beautiful terrace formations all along their margins. In connexion with the Orere Stream, a curious feature is developed at the Orere Settlement sawmill. This consists of a wide basin or depression flanked by steep hills; and in this depression the stream has developed a right-angle bend from north to east, the cause of which is rather obscure.

It may be suggested first that the Upper Orere Stream followed a fault, here postulated as defining the west flank of Kohukohunui, and that it was captured later (still at an early stage in the stream's history) by a stream working headward from the east, and that the broad open valley or basin at the settlement represents a result of some greater ease of weathering of the underlying rock. The small outlet gorge east of this hollow is partly, of course, a result of rejuvenation by uplift that has left its mark as terraces along the Lower Orere Stream.

Apart from their terraces, the Aro Aro and Lower Wairoa Streams have no extraordinary features.

Economic Geology.

The Clevedon district has few deposits of economic value, and the only ones put to any use at the present time may be dealt with under two headings:

1. *Greywacke.*

This rock covering the major portion of the district is used extensively for road-metal, being very hard and wearing moderately well. It is commonly termed "blue metal" and is not used otherwise than as roading material.

2. *Manganese.*

At the head of Mangatawhiri Valley, near Otau, are two deposits of manganese, one of which may prove of some value. The first, worked by Mirandite Products Ltd., of Christchurch, is situated about 1½ miles south of Plow's Farm, and the other, on Piggot's Farm, a further 2 miles to the south.

Both these deposits have been examined by officers of the New Zealand Geological Survey, Mr. J. Healy, in 1935, and Mr. E. O. Macpherson, in 1940, and accounts of their investigations published. (Healy, 1937, and Macpherson, 1941.) Mr. Healy estimated that the trenching carried out at Mirandite Product Ltd's claim proved about 9,000 tons of high-grade ore (oral communication).

CONCLUSION.

This paper offers a unified description of the geology of an area that has received little attention from geologists, probably on account of the difficulties of access. Although the major portion of the area is constructed of somewhat unvaried greywacke, yet the topographical features and fluviatile deposits present many topics of interest.

The writer is deeply indebted to Professor J. A. Bartrum, of Auckland University College, for his invaluable aid and advice in the compilation of this paper.

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The Basic Igneous Rocks of Eastern Otago and their Tectonic Environment.

By W. N. BENSON.

With Chemical Analyses by F. T. SEELYE.

[*Read before the Otago Branch, November 20, 1941; received by the Editor, November 27, 1941; issued separately, June, 1942.*]

PART II.

(i) The Distribution of the Late Tertiary (Pliocene) Eruptive Rocks in Eastern Otago in Relation to Regional Tectonics.

(ii) Petrographical Nature and Chemical Composition of the Late Tertiary Igneous Rocks in the Relatively Stable and Moderately Deformed Regions around the Dunedin Central Region.

(iii) Appendix. Note on the Geology of Kauroo Hill.

(i) THE DISTRIBUTION OF THE LATE TERTIARY (PLIOCENE) ERUPTIVE ROCKS IN EASTERN OTAGO IN RELATION TO REGIONAL TECTONICS.

In Part I (Benson, 1941a) of this paper, it was shown that there has been a noteworthy continuity in the general tectonic character of the several diverse portions of Eastern Otago since Middle Cretaceous times. The broad depression of the Maniototo Plain, and the narrower Taieri-Waihola and Tokomairiro plains give evidence of repeated "negative" or downward movements throughout this period and the same is true of the narrower coastal zone now covered by thick marine sediments extending from Dunedin to Oamaru. It was further shown that in general the highest of the basalt-covered ridges, thrust up during post-Pliocene crust-movements, had been "positive" areas during the period immediately prior to the eruption of the basalt, since the Cretaceous-Lower Tertiary sediments beneath their basalt-caps, if present at all, are very thin.

Mapping within the Dunedin or Central Region, the details of which cannot here be elaborated but are sketched below, shows that intermittent crustal movements occurred during the very diversified Pliocene eruptive activity, and reached their climax at its close. It seems, therefore, permissible to consider, at least tentatively, that the extent of deformation which has occurred in any region since the Late Tertiary† peneplanation is some measure of the instability of the crust in that region during the period of Pliocene eruptive activity. Plate 36 of Part 1 of this paper indicates that three major divisions may be recognised in Eastern Otago, which, though not sharply separated from one another, may characterise three successive degrees of mobility of its crust.

† Footnote, added May 20, 1942: The Late Tertiary erosion-surface in Eastern Otago has, for certain inconclusive reasons, been tentatively termed the "Late Miocene Peneplain" in Part I of these papers. While this Part II was in the press, however, there appeared Wellman and Willett's (1942) paper, in which it is held that this erosion-surface was formed during later Pliocene times. If this were so, the greatest age which could be assigned to the igneous rocks discussed herein would be very late Pliocene. It would seem desirable, moreover, to retain for the present the original and not too specific term Late Tertiary for the erosion-surface upon which they rest.

The Relatively Stable Region comprises the western portion of the area shown in Plate 36. It has certainly not escaped deformation, but has been arched into the broad warpings of the Rough Ridge, Lammermoor, and Rock and Pillar Ranges, which only in their northern portions are broken by close-spaced faults. The same may be true to a smaller extent of the intervening Upper Taieri syncline, and is markedly true of the long, only gently warped, Tuapeka-Waipori-Strath Taieri depression with its eastward extension into the Barewood Plateau.

The Moderately Deformed Region sweeps around the eastern and north-eastern margin of the former region, and is characterised by much narrower fault-folds and more closely-spaced faults. (See Part I, p. 213, and Plate 36.) Lying between the Relatively Stable Region and the coast, it extends from the Clutha River embracing the Tuakitito-Tokomairiro-Waihola-Taieri syncline, and its bounding anticlinal ridges, and sweeping northwards, leaving the Dunedin Central District on the east, it bends north-westward to include the watersheds of the Waikouaiti and Shag Rivers and the northern portions of the Rock and Pillar Range and of the Maniototo Plain with a southward projection into the broken ridges east of the Strath-Taieri Depression. Across the Shag Valley,* the lava-capped Kakanui Range must also be included in this region, which may be held to extend to the Kakanui Valley near Kauroo Hill (Part I, Plate 36, Loc. 100). In view of the deep differential erosion of the varied Lower Tertiary formations extending across the Lower Kakanui Valley to beyond Oamaru, one cannot determine the degree of deformation the Tertiary peneplain has suffered here; but it seems possible that, though the deformation was rather vigorous in Miocene times prior to the Late Tertiary planation, the Oamaru area has been *relatively* stable since then.

The *Strongly Deformed Region* is that forming the Dunedin or Central Region and comprising the large promontories on either side of Otago Harbour lying east of the Moderately Deformed Region which here is bounded not by the coastline, but by a line almost co-linear with the general trend of the coastline, namely, the seaward (western) slopes of the Silver Stream and South Waikouaiti valleys. Deformation of the earth's crust since Miocene times within this region has been much greater than in the others, its relatively high mobility being marked by strong folding and faulting both on approximately N.E.–S.W. or E.N.E.–W.S.W. axes and on N.N.W.–S.S.E., and by strong regional downwarping and subsidence, all of which movements appear to have been in progress before, during and especially after the volcanic activity, as may be inferred from the data presented on Plate 36, figures 1 and 2, of Part I of these papers and fig. 1 of a previous paper (Benson, 1940).

Tectonic Regions Petrographically Characterised.

The Relatively Stable Region comprises about fifteen hundred square miles within the area considered. It is almost devoid of

* The account of the geomorphology of this valley given in Part I of these papers with brief reference to Cotton (1922), should be supplemented by reference to the earlier and fuller discussion by Cotton (1917).

Late Tertiary igneous rocks. A doubtfully recorded dyke at Locality 21, two small flow-residuals at Localities 27a and 28 and possibly a plug or flow at the (unvisited) Trig F, three miles west of Locality 28, are all that are known within Central and Western Otago, and together cover less than a fifth of a square mile. They comprise normal and slightly zeolitic olivine basalts. In the area around Oamaru at the north-eastern extreme of our map, though it contains a great development of probably older Tertiary to Late Oligocene basic tuff, sills, dykes and pillow-lavas and was strongly deformed prior to the Late Tertiary peneplanation, there are no known post-Miocene igneous rocks.

The Moderately Deformed Region, as here defined, covers about nineteen hundred square miles. It contains almost all of the rocks dscribed in this series of papers. The eighty-seven localities from which the specimens have been derived contain breccias and tuffs, dykes, plugs and possibly domes of small size, at least one gravitationally differentiated sill (at Locality 17, to be described elsewhere), but chiefly residuals of formerly more extensive but relatively thin flows. There is rarely evidence of the occurrence of more than three or four flows in sequence, or of a total thickness of more than three hundred feet of igneous rock. The largest residual of a single sheet, the Waipiata doleritic basalt (Localities 64–70 and perhaps 71), covers nearly twelve square miles and may have been originally much more extensive. Next in area (six square miles) is the flow-complex on the summit of the Kakanui Range (examined by Brown and Marwick), which, however, contains one originally more extensive flow, outliers of which, at Localities 74 and 95 to the west and east of the main mass, are more than eleven miles apart. Similarly, Service (1934) has shown that several of the flows occurring in the relatively small residual masses in the Goodwood area had formerly a rather wide extent. Most of the remaining flow-residuals cover individually only a small fraction of a square mile. The total area of basaltic rocks now remaining in this region is approximately forty-three square miles, but their former extent may have been several times as great. Except in the cases mentioned, there is little evidence on which to base an estimate of the former extent of a flow indicated by the petrographical similarity of material derived from many isolated residuals; because, as yet, only a rapid reconnaissance-survey has been made over the greater part of this region. The contrast between the rarity of known dykes in this large, hastily-examined region, and their abundance in the more closely-studied Dunedin Central Region, though it will doubtless be lessened by further work, is probably real, and calls for caution against assuming an excessively wide extent of basaltic flows or much fissure-eruption in the Moderately Deformed Region. The close proximity of some sheet-residuals to known faults (not always in the fault-angle depressions) suggests that such faults may have been, or may have been near the channels of effusion (e.g. Localities 29–31, 35–36) and gives further hint of the only moderate maximum extent of the flows. It seems probable, however, that in general the lavas were poured out over surfaces usually of low relief, and that the chief fault-movements occurred after such effusions.

The variety of igneous rocks present in this region, while considerably greater than that among the few occurrences in the Relatively Stable Region, is nevertheless much less than in the Strongly Deformed Region. The following limits for the chief oxides present are shown by nineteen representative analyses by Mr. F. T. Seelye, which are tabulated below (Table V).

TABLE I.

Range of Compositions of Igneous Rocks of the Moderately Deformed Area.

	Per Cent.		Per Cent.
SiO_2	40.01–47.69	Na_2O	2.53–6.24
Al_2O_3	11.78–17.77	K_2O	0.64–3.04
Fe_2O_3 + FeO	11.38–16.40	P_2O_5	0.17–2.24
MgO	3.15–10.06	TiO_2	1.08–3.96
CaO	5.85–13.14	MnO	0.17–0.29

For obvious reasons it is not possible to estimate with any degree of probability the original volume of each type of rock present or the proportion between such volumes. The following table indicates, however, the number of localities out of the above total of 87 wherein the various types of volcanic rocks have been detected.

TABLE II.

Normal Basaltic Rocks.	Localities.
Finely granular olivine and/or augite basalts are known at	30
Feldspar augite olivine basalts	8
Feldspar basalts	8
Coasely granular olivine-bearing doleritic basalts	22
Intersertal Dolerite	1
Ankaramite	6
More Alkaline Basic Rocks.	
Zeolitic, olivine-bearing doleritic and fine grained basalts	10
Mugearite	2
Atlantites and basanites	14
Olivine theralite	1
Olivine nephelinite	3
Limburgite	3
	33

Since the normal olivine and olivine-augite basalts are probably present in greater volume proportion than the above figures indicate, and there are no analyses of the richly feldspathic basalt (apart from the mugearite), an average calculated from the analyses now available, taken in the above proportions, affords the nearest approach that can be made at present to the average composition of the igneous rocks in the Moderately Deformed Region, and may be substituted for the average composition of the rocks in this region previously published (Benson, 1941, p. 541, Table Ie) when only five analyses were available. The new average (a) is given in Table III below, together with (b) a crude average composition of the basaltic rocks of the Dunedin Central region.

TABLE III.

	(a)	(b)		Norm of (a)	Norm of (b)
SiO_2	46.16	48.25	Orthoclase	7.78	8.90
Al_2O_3	15.32	16.11	Albite	21.48	28.82
Fe_2O_3	3.50	6.01	Anorthite	21.13	23.91
FeO	9.67	8.73	Nepheline	5.96	0.28
MgO	7.25	4.07	Augite	18.79	18.83
CaO	9.58	9.96	Olivine	14.80	6.15
Na_2O	3.74	3.46	Magnetite	5.10	8.82
K_2O	1.34	1.54	Ilmenite	4.56	4.41
TiO_2	2.45	2.35	Apatite	1.34	1.01
P_2O_5	0.65	0.36	Plagioclase =	Ab_{52}	Ab_{56}
MnO	0.21	0.21*			

* One determination only.

It must be emphasised, however, that as all but one of the basalts in the Dunedin region which are considered in the averaging were those from the Otago North Head Series analysed by Marshall (1914) in which the feldspathic basalts are rather more abundant, and the richly olivinic and augite-rich types are proportionally less abundant than is probably true of this region as a whole, the distinction between the average composition of the basaltic rocks of the Central and peripheral regions is probably less than here appears.

The Strongly Deformed Central Region.

Here, the conditions as to the range of petrographical character, chemical composition, and relative abundance of the igneous rocks is very different from that in the less deformed regions. Of the total area of a hundred and seventy square miles included within the Strongly Deformed Region, one hundred and ten are covered by Pliocene volcanic rocks; and the distribution of scattered outliers or residual boulders suggests that almost the whole of the area was at one time covered by volcanic rocks. The range of chemical composition indicated by the fifty-eight good analyses which are available, (including several by Mr. F. T. Seelye which are as yet unpublished), is shown by the following table.

TABLE IV.

Range of Chemical Composition of Igneous Rocks in the Dunedin Central Province.

	Per Cent.		Per Cent.
SiO_2	44.00–66.04	Na_2O	1.74 –8.82
Al_2O_3	12.92–20.80	K_2O	0.46 –7.09
Fe_2O_3 + FeO	0.12–11.00	P_2O_5	0.11*–1.68
MgO	* 0.12–11.18	MnO	0.14*–0.26
CaO	0.96–10.80		

* Lowest determined values, but probably in excess of amounts present in certain incompletely analysed trachytes.

As shown in Section D of Fig. 2 in the first part of this series of papers, the basement schists and overlying Upper Cretaceous-Middle Tertiary Sediments in this region were folded into a series of anticlines and synclines with an eastwardly-increasing depth of depression prior to the Late Tertiary peneplanation, which cut a surface obliquely through these sediments and merging westward into approximate coincidence with the Cretaceous peneplain

ent in the schists. The presence of Miocene limestone truncated by the later peneplain under its lava-covering and locally exposed in the Otago Harbour area near Port Chalmers and Hooper's Inlet (see also Benson, 1940, Fig. 1) marks the region of greatest depression of the basement-formations within the Dunedin Central region. It is also the area where the major eruptions commenced, and about which subsequent eruptive activity appears to have been very vigorous as indicated by the concentration of a very varied series of dykes and immense breccia-filled vents in this vicinity, though many outlying centres of explosion and effusion were formed during the prolonged and diversified sequence of eruptive activities the details of which will be given elsewhere. An outline thereof has already appeared (Benson, 1934, 1941), and is here given in a slightly modified form.

The earliest eruptive materials now occurring *in situ* are anorthoclase trachytes. They rose in small amount through several minor vents on the south-western and north-western margin of the Dunedin Central area, breaking through tectonically elevated areas, but were erupted in very large amount in the central originally-depressed Port Chalmers-Hooper's Inlet region, where trachytic agglomerates and tuffs associated with small trachytic flows and cut by very many trachytic dykes built up a low cone nearly two cubic miles in volume. In the centre of this mass, near Portobello, the trachytic agglomerate contains a few fragments of feldspar basalt and trachyandesite (?) the only indication of pre-trachytic effusions. Before the trachyte magma was exhausted, basaltic magma rose chiefly from a centre a few miles south of the main area of trachytic eruptions. Its expulsion commenced with the formation of massive agglomerate followed by finer grained tuffs and more widespread flows of very basic olivine-basalt, and olivine-augite basalt. The earlier members of this series of flows were invaded by the latest trachytic dykes, and among the later basaltic flows of this series is a kaiwekite which the writer interprets as a trachyte-basalt hybrid, in which the trachytic material is usually in excess. Occasional small flows of basanite, trachybasalt and trachyandesite, and rarely of phonolitoid trachyte, the "phonolite" of Flow No. 2 at North Head (Marshall, 1914), indicate a change of magmatic differentiation from a trachytic towards a phonolitic pole. Some crust-movement was in progress and the thinning out of the basaltic agglomerate and tuffs (in so far as it may not be due to its moulding against the trachytic cone) suggests the rise of two low anticlinal ridges running in an E.N.E. and N.N.W. direction respectively and intersecting a little south of Portobello. Here the movement was accentuated at the close of this eruptive phase by the intrusion of laccolites of phonolite and nepheline syenite porphyry, followed by immense explosions from a series of now breccia-filled vents along the axis of the N.N.W. anticlinal fold. The material ejected from these vents was carried far, especially towards the north, west and south-west, and accumulated to form massive mud-flow conglomerates locally more than a hundred

feet thick. Their distribution suggests that a synclinal warping then connected the sites of the present Otago Harbour and Taieri Plain synclines.

The second major eruptive phase included a more widespread and diversified series of effusions than the first. The magma may have been thrust into separate reservoirs from which the differentiates, expelled from time to time, produced a complex sequence of interdigitating flows of varied basalts (preceded by basaltic agglomerates in the west and north), of phonolites (including the particularly widespread and voluminous Logan's Point and Waitati flows of what must have been very mobile magma), trachybasalts and trachyandesites, and olivine dolerite together with minor amounts of atlantite, mugearite and kulaite. The later products of this phase are chiefly in the western portion of the Dunedin region, and there are other features suggesting some elevation in the Port Chalmers area during this eruptive phase, as well as indications of a slight arching where is now the Flagstaff-Swampy Ridge. The second phase closed with another explosive eruption of fragmental, largely phonolitic, but also basaltic material from a vent now concealed beneath later flows near the summit of Mount Cargill, which seems to have been then a rising ridge. The greatest thickness of the water-borne detritus conveyed south-westwards from here occurs near the Lower Leith Valley, which seems to have then had a tendency towards synclinal depression.

This tendency spread into the middle and upper Leith Valley during the immediately following third eruptive phase. Basaltic eruptions broke out near here, spreading in most directions, but particularly to the south-west over a much more restricted area than the basalts of the second eruptive phase. A little trachybasalt, atlantite and basanite occurs among these flows, which are thickest in the middle Leith Valley, where there is a noteworthy amount of a fine-grained basaltic tuff and "fire-fountain material," like that of Halemaumau in Hawaii—the comparison is due to Dr. H. T. Stearns (priv. com.). Above these follows an extensive flow of cossyrite phonolite extending over six miles to the north-east from Mount Cargill overlapped by a related flow of olivine-bearing phonolite, rendered hybrid by absorption of basaltic material, and extending over eight miles to the south-west.

Crust-movements became much more vigorous and the compressive movements greatly accentuated the anticlinal and synclinal ridges which, modified by erosion and partly drowned, constitute the present hills, valleys and embayments. The latest extrusions of magma accompanied these movements. A small plug of normal olivine basalt rose into a fault-plane breaking the sharp Mount Cargill anticline, and a phonolite-dyke invaded the reverse fault in the steep eastern flank of the asymmetric anticlinal Flagstaff-Swampy Ridge.

Distribution of the Pliocene Volcanic Rocks in the Relatively Stable and Moderately Deformed Regions of Eastern Otago with Notes on the Localities from which were obtained the materials studied.

Petrographical details will be given elsewhere supplementing the accounts by Marshall and others of the varied rocks, the sequence

of eruption of which within the unstable Dunedin Central Region has been sketched above. The remainder of this paper is concerned with the less varied characteristics of the hitherto little studied Pliocene igneous rocks in the regions peripheral to the Dunedin Central Region, which, on rather inconclusive grounds are thought to be probably coeval with the main (second) eruptive phase of this region. The brief statement of the types of rocks occurring at each specified locality will be followed by a summary of the general features of each petrographic type developed, and a table of chemical compositions thereof.

The map (Plate 36 of Part I of these papers) illustrates the distribution of all known masses of Pliocene igneous south and south-west of the Shag River valley and the positions of over 100 localities outside the limits of the Dunedin (Central) Region from which rocks, which have been microscopically examined, were collected by Andrew, Benson, Dunne, Hutton, Marshall, Ongley, Paterson, Service, Turner or Williamson. The name of the collector thereof has been indicated by the initial letter of his surname in the list given below. In the case of slides lent by the Geological Survey for the purposes of this study, the letter "P." is placed before the registered number of the slides, as is done in the Survey's official register of petrographical slides. Numbers without such prefix are those in the slide-register of the Geological Department of Otago University. Some rocks are represented by slides in both collections. The gift to the University of the slides studied and described by Dr. Andrew, Paterson and Service is gratefully acknowledged.

List of localities from which were derived rocks studied, their collectors, modes of occurrence, petrographic characters, registered slide numbers, and analyses as given in Table V:—

1. Mouth of Taratu Coal Mine, Kaitangata. (O.). Dyke. Intersertal dolerite. (P. 5560.)
2. Head of Waronui Creek. (O.). Dyke. Atlantite. (P. 5596.)
3. Cook's Head (or Cook's Nose), Tokomairiro Beach. (O.). Plug. Fine-grained zeolitic olivine basanite (or atlantite). (P. 4158.) Analysis No. 14.
4. Dunn's Quarry, two miles south-east of Milton. (O.) Plug. Olivine augite basalt. (P. 5561.)
5. End of Waronui Railroad. (O.) Dyke. Ankaramite. (5053, P. 4158.)
6. Head of Noble Creek, Akatore S.D.* (O.) Plug. Zeolitised basanite or atlantite with deuteric carbonates. (5048, P. 4163.) Analysis No. 16.
7. Head of Narrowdale Creek, five and a-half miles east of Milton. (O.) Dyke. Atlantite. (P. 4143.)
8. Capping of Table Hill, extending two to six miles north-west of Milton. (A.M.) Flow fifty feet thick resting on thin stratum of quartz-conglomerate above schist. Coarse-grained zeolitic dolerite-basanite (*fide* Marshall, 1918, pp. 63–4) and doleritic basalt. (5682.)

* S.D. = Survey District.

9. One and a-half miles west of Milburn Post Office. (O.) Flow resting on schist and dipping south-east. Doleritic basalt. (5050, P. 5167.)

10. Road-cutting half a mile north of Akatore bridge. (B.) Dyke split into three narrow sheets invading sandstone adjacent to strong fault which brings sandstone down against semi-schist. Augite olivine basalt. (5073, 5074.)

NOTE.—The semi-schist on the coast two miles south of this spot contains a lenticle of limestone showing traces of radiolaria and foraminifera (Benson and Chapman, 1938).

11. "Strains," one mile and a quarter south-east of Milburn railway station. (A.O.B.) Sediments (sandstone, greensand and limestone), overlain by flow of limburgite (5054, 5072, 5693, P. 4139. Analysis No. 22), succeeded by flow of weathered dolerite; all steeply dipping against fault-plane. See Fig. 1.

12. "Kapiti," a mile and a quarter east of Milburn railway station. (A.B.) Faulted limestone overlain by flow of limburgite (5069, 5694), covered by flow of ankaramite (5702).

13. Milburn Hill and Stony Knob. (A.M.B.) Sediments and limestone overlain on the southern side (above Milburn limestone quarry) by flow of limburgite (5095–6); followed by finely granular zeolitic basalt (5085, 5705, 5707–9, 5712 and ? 5703, 5711, 5726), succeeded by zeolitic basanites of medium grain-size (5082–4, 5686, 5710, 5723) and capped by more finely granular iddingsitic zeolitic basalt (5086–7, 5704, 5706). See Fig. 1.

14. Cemetery Hill, half a mile north of Clarendon railway station. (A.M.O.) Zeolitic basalt (5689), resting on schist followed by less finely granular zeolitic basanite (5690–1). Analysis No. 17. See Fig. 1.

15. Summit of Trig. D, three and a quarter miles west-north-west of Clarendon railway station. (B.) Flow-remnant resting on quartz-conglomerate on schist. Olivine basalt (5075).

16. Summit of Trig. L, two miles north of Clarendon railway station. (A.O.) Flow-remnant resting on schist. Olivine basalt (5051, 5692, P. 4162).

17. Promontory of Waihola Hill Trig., one to four miles west of Waihola township. (M.O.B.) Flow of olivine basalt (5052, 5065, 5079, P. 4164, P. 4165), overlapping westward from Abbotsford Mudstone on to schist. Capped in promontory by flow of zeolitised atlantite (5070, 5071), from which it is separated by the westward tapering end of a gravitationally differentiated sill of olivine theralite (5060, 5061, 5064, 5068, 5698–5700) to be described in detail in Part 3 of these papers. Analyses Nos. 18, 19.

18. One hundred yards west of Waihola township. (O.) Plug. Olivine basalt (5791, P. 4149).

19. Near Ferry Hill Trig., two miles north-east of Waihola township. (O.) Plug. Ankaramite (P. 5597).

20. North side of mouth of Taieri River. Collector unknown. Dyke. Very decomposed trachytoid feldspar basalt (5036).

    Note.—The fabric of the semi-schist invaded by this dyke has been investigated by Turner (1940, p. 53).

21. Waitahuna Hill. (M.) Pebble, occurrence *in situ* unknown. (Dyke?) Vesicular feldspar basalt (*fide* Marshall, 1918, p. 64).
22. Trig. O, four miles north of Waihola township. (O.B.) Stratified mass of coarse basaltic agglomerate (5715) at least 300 feet thick, dipping to the south-east at 30° and resting on schist.
23. A quarter of a mile north-east of the Factory bridge at Henley. (O.B.) Dyke. Invading Kaitangatan sediments. Ankaramite (P. 5598).
24. Trig. O, three-quarters of a mile south-south-west of Otokia railway station. (O). Plug invading Kaitangatan sediments. Ankaramite (P. 5576).
25. Beside railway line half a mile south-west of Allanton station. (O.) Plug? Zeolitic dolerite (P. 5577).
26. Ridge half a mile north-east of Allanton railway station. (O.) Flow dipping north-west and resting on Abbotsford mudstone. Very fine-grained basalt (P. 5584).
27. Summit of Mount Hyde, Trig. X, Mount Hyde S.D. (M.) Flow about 30 feet thick resting on thin layer of quartz-conglomerate on schist. Olivine basalt (5670).

    Note.—The structure of the schists in this neighbourhood has been described by Turner (1940, pp. 84–93, 185–188).

27a. On hill culminating in Trig. F, Mount Hyde S.D. (B.) Basalt flows in all about 200 feet thick resting on 100 feet of sandstone above schist. (i) At Trig. F. Olivine basalt (5023). (ii) A quarter of a mile west of Trig. F. Zeolitic basalt (5022). (iii) Half a mile south of Trig. F. Olivine basalt (5024).

28. Summit of Mount Stoker, Trig. G, Nenthorn S.D., nine miles east of Middlemarch. (B.) Columnar flow 100 feet thick resting on thin layer of sandstone above schist. Fine-grained olivine basalt (5646).
29. Yellow Hill, Trig. K, Nenthorn S.D. (B.) Flow over 200 feet thick resting locally on vesicular basaltic agglomerate above thin sandstone and conglomerate on schist. Fine-grained olivine basalt (5642).
30. Peat Moss Hill, one and a-half miles south-east of Trig. K, Nenthorn S.D. (B.) Flow about 100 feet thick resting on a few feet thick of sandstone, dipping gently westwards and faulted down against the basalt on Yellow Rock Hill. Fine-grained olivine basalt (5657).
31. Hummock, Trig. D, Hummock S.D. (B.) Flow about 150 feet thick on a thin conglomerate on schist. A continuation of the Yellow Hill flow with down-faulted residuals of the Peat Moss Hill flow at its eastern foot. Fine-grained olivine basalt with abundant olivine nodules (5656).

32. Trig. HH, north-west corner of Waikouaiti S.D. (B.) Columnar flow about 80 feet thick dipping west-north-west at 10° and resting on thin ferruginous sandstone. Fine-grained olivine basalt (5669) comparable with that at Locs. 29, 30, 31.
33. Stony Hill, three-quarters of a mile north of Loc. 32. (B.) Flow (on sandstone?) on schist. Continuation of the flow on Trig. HH. Medium-grained olivine basalt (5662).
34. Hill a mile and a half north-east of Trig. HH, Waikouaiti S.D. (B.) At least two flows about 250–200 feet thick in all. Lower flows on the southern spur resting on thin Abbotsford Mudstone above thin sandstone and schist. Medium-grained olivine basalt comparable with that at Loc. 36, but a little richer in augite (5655).
35. The Ram Rock, half a mile S.S.E. of Trig. E, south of Hummockside S.D. (B.) Dyke probably rising along the fault plane running E. of Scratchback Hill and feeding the small dome (?) composing this mass. Nepheline basanite (5659).
36. Scratchback Hill, Trig. E, Hummockside S.D. (B.) Two flows, in all about 300 feet thick, on north end of hill, resting on Abbotsford Mudstone above thin white sandstone on schist. Lower flow: Ankaramite containing xenoliths of schist (5660, 5667) covered by:—
    Upper flow: Coarsely granular olivine augite basalt with a little zeolite in groundmass and vesicles (5664, 5666).
37. Mount Watkin, Trig. F, Hawksbury S.D. (S.) Two flows together about 400 feet thick, resting on Abbotsford Mudstone and thin sandstone on schist. Lower flow trachytic feldspar basalt (2026), overlain by feldspar-augite-olivine basalt (2037–2038).
38. Derdan Hill, Trig. D, Hawksbury S.D. (B.S.) Flows resting on Caversham Sandstone and normal sequence of sediments with schist at base. Lower flow coarsely granular doleritic basalt about 100 feet thick (2014), invaded by dyke feeding a covering flow of trachytic feldspar basalt (2016–2020).
39. Hawksbury Hill, a mile and a quarter E.N.E. of Trig. D, Hawksbury S.D. (S.) Flow about 260 feet thick resting on Caversham Sandstone, etc. Pilotaxitic feldspar-augite-olivine basalt (2021, 2022).
40. Mount Mackenzie, Trig. J, Hawksbury S.D. (S.) Three flows 250–300 feet thick in all, resting on sandstone on schist. Lowest flow. Feldspar augite olivine basalt (2027, 2028), covered by porphyritic dolerite (2035), and capped by pilotaxitic feldspar-augite olivine basalt (2039).
41. Mount Trotter, a mile and a half north of Trig. J, Hawksbury S.D. (S.) Basaltic tuff (?) 100 feet thick resting on Abbotsford Mudstone, etc., and capped by porphyritic dolerite (2034) about 150 feet thick.
42. Middle Mount, two miles W.N.W. of Trig. Q, Hawksbury S.D. (S.) Flow about 200 feet thick on Abbotsford Mudstone, etc. Porphyritic dolerite (2031–2033).

43. Taieri Peak, Trig. R, four miles west of Palmerston. (P.) Plug (?) or flow-residual about 150 feet thick on sandstone on schist. Augite olivine basalt (5671, 5678). Also a dyke of vitric basaltic breccia (5681).

44. Mount Pleasant, Trig. Q, Hawksbury S.D. (S.) Two flows in all about 230 feet thick resting on thin Abbotsford Mudstone on basal sandstone, etc. An olivine augite basalt (2050) covered by flow of ankaramite (2045–9).

45. Mount Royal, Trig. T, Hawksbury S.D. (S.) Caversham Sandstone (with the usual sedimentary series below covered by basalts, etc., about 450 feet thick in all, comprising a basal flow of feldspar basalt (2023–5) succeeded by basaltic tuff, porphyritic dolerite (2029, 2030), basaltic tuff and, as the highest flow, a trachytic feldspar basalt (2040–2).

46. Bobby's Head, Trig. M, Hawksbury S.D. (S.) Goodwood limestone with normal sequence beneath, invaded by dyke of trachytic feldspar-augite-olivine basalt feeding a flow nearly 300 feet thick capping the limestone (2043, 2044). The margin of the dyke, deeply weathered and bleached against the invaded limestone, bears a considerable resemblance to some trachytic tuff in the Dunedin Central Region. The writer must take responsibility for Service's unchecked acceptance of the suggested comparison.

NOTE.—All the above data concerning localities 37–42 and 44–46 are based on Service's (1934) paper.

47a. Puketapu, Trig. O, Moeraki S.D., one mile S.E. of Palmerston. (P.) Feldspathic basaltic breccia nearly 280 feet thick on Caversham Sandstone, etc., invaded by a dyke of slightly zeolitised doleritic augite olivine basalt [5680 = Paterson's (1941, p. 49) "analcite-bearing dolerite"] and overlain by a flow of olivine augite basalt about 100 feet thick, with more pyroxene in the lower (5675) than in the upper (5677) portion.

47b. Little Mountain, one mile south-east of Puketapu. (P.) Dyke of feldspar olivine basalt (5093) invading plug (?) of vitric basaltic breccia.

48. Smyler Peak, Trig. P, a mile and a half west-south-west of Palmerston, Moeraki S.D. (P.) Plug (?) invading Abbotsford Mudstone. A rather coarsely granular feldspar olivine basalt with strongly marked flow structure (5672–4, 5679 = P. 5988). Paterson's (1941, p. 49) "olivine dolerite."

49. Janet Peak, Trig. V, two miles north of Palmerston, Moeraki S.D. (P.) Plug (?) or sheet-remnant about 100 feet thick rising through or resting on Burnside Mudstone, etc., capped by trachytic basalt tuff 100 feet thick. Medium-grained feldspar (olivine augite) basalt (5676, P. 3824).

NOTE.—The rocks from localities 43, 47, 48 and 49 were collected and described by Paterson (1941). The structure of the underlying schist has been described by Turner (1940, pp. 169–180).

50. Small Conical Hill by Sheepwash Creek, three miles east of Middlemarch, Strath-Taieri S.D. (B.) Dome rising about 150 feet above the surface of the schist. Fine-grained olivine nephelinite (5649). Analysis No. 20.

NOTE.—The structure of the adjacent schist has been described by Turner (*op. cit.*, p. 180).

51. Small Cone half a mile south of Trig. G and five miles east-north-east of Middlemarch, Strath-Taieri S.D. (B.) Volcanic dome about 150 feet high or flow-remnant on schist. Mugearite (5651–2). Analysis No. 1.

52. Smooth Cone, Trig. G, five and a half miles north-east of Middlemarch, Strath-Taieri S.D. (B.) Dome or flow-remnant rising through or on schist. Porphyritic mugearite (5643).

NOTE.—McKay's (1894) map-indication of the presence of sediments beneath the volcanic rocks at the last two localities has not been confirmed.

53. Slip Hill, Trig. J, five and a half miles east of Middlemarch, Strath-Taieri S.D. (B.) Flow dipping west and resting on sandstone above schist. Fine-grained olivine basalt (5648).

54. Hill a mile and a half south-east of Trig. J., Strath-Taieri S.D. (B.) Columnar flow about 50 feet thick resting on very thin sandstone about 100 feet below the local general level of the Late Tertiary peneplain. Carbonated olivine basalt (5645).

55. Bald Hill, Trig. H, five and a half miles east-south-east of Middlemarch, Strath-Taieri S D. (B.) Flow on schist possibly separated therefrom by a very thin layer of sandstone. Fine-grained olivine basalt (5658).

56. County road-metal quarry, Shark Hill, by Moonlight Flat, Budle S.D. (B.) Small extrusive dome rising through sandstone showing transition in quarry face from a lower medium-grained hypocrystalline nepheline basanite (5653) into an overlying marginal obliquely columnar phase of very finely granular zeolitic augitite (5647).

57. Station Hill, five chains south-east of Trig. S in the S.E. corner of Rock and Pillar S.D. (W.) Dyke (?) or small flow-residual in or on sandstone. Ankaramite (158 = P. 3630). (See Turner in Williamson, 1939, p. 67.)

NOTE.—This mass of igneous rock is not indicated on the official map. (Williamson *op. cit.*, Sheet 7.)

58. Highlay Hill, Trig. GS, Highlay S.D. (W.) Flow on sandstone. Fine-grained zeolitic atlantite (193 = P. 3646). (Described as fine-grained olivine basalt by Turner, *loc. cit. supra.*)

59. Donaldson's Coal Pit, 60 chains north-west of Trig. G, Rock and Pillar S.D. (W.) Flow resting on sandstone. Zeolitic atlantite described as zeolitic olivine basalt by Turner (*loc. cit. supra*) (168 = P. 3639). See Analysis No. 12.

60. Hyde, one and a half miles north of railway station and thirty chains east-north-east of Trig. G, Rock and Pillar S.D. (B.) Flow on sandstone 50 ft. thick. Fine-grained olivine (augite) basalt (5665).

61. Tiroiti. (a) Half a mile east-south-east of railway station and seventy chains north-west of Trig. F, Rock and Pillar S.D. (B.) Flow on thin sandstone, the lowest and marginal portion of an uninvestigated flow-complex possibly surrounding vent (*fide* Williamson, 1939, p. 64). Olivine basalt with few phenocrysts (5661).

(b) Thirty chains north-west of Trig. F. (W.) Probably overlying (5661) and related to Waipiata doleritic basalts (Locs. 63b–70), and marking their eastward limit. Coarse-grained doleritic olivine basalt (153 = P. 3658) described by Turner (*loc. cit.*, p. 66).

(c) Two and a-half miles north-east of railway station on boundary of Rock and Pillar S.D. (B.) Flow on sandstone. Fine-grained olivine basalt (5668) comparable with that at Locs. 60 and 61a.

62. Tiroiti. Three miles east of railway station, Trig. O, Rock and Pillar S.D. (W.) Flow on sandstone. Medium-grained olivine augite basalt (P. 3651).

63. Kokonga. Two miles east-north-east of station and 72 chains west-south-west of Trig. O, Swinburn S.D. (W.) Flow on sandstone. Analysis No. 15. (See Williamson, 1939, p. 65.) Too decomposed for precise determination, but suggestive of zeolitised atlantite. No specimen available for microscopic study.

64. Kokonga. (a) Half a mile east of railway station. (B.) Massive flow of coarse doleritic olivine basalt (5663).

(b) Exact locality uncertain. Large. "Olivine nodule" from basalt collected and presented by Mrs. N. Kingston, M.Sc. (5100), to be described in structural detail elsewhere by Dr. F. J. Turner.

65. Kokonga. On main road two and a-half miles west of the railway station. (B.) Massive flow similar to 64 (a).

66. Kokonga. On main road three and a half miles west of railway station. (T.) Massive flow as at 64 (a) and 65 (5055).

67. Kokonga. (a) Three miles south-west of station, 40 chains north-west of Trig. L, on southern boundary of Maniototo S.D. (W.) Massive flow coarse doleritic olivine basalt (162 = P. 3598). (See Turner in Williamson, 1939, p. 67.) Analysis No. 3.

(b) At Flat Cap = Trig. L. (W.) Massive flow on Miocene (?) sand, etc. See Analysis No. 4. Probably the Waipiata doleritic olivine basalt. Specimen not available.

68. Ranfurly. Main road six miles east of railway station. (B.) Northern extreme of the Waipiata doleritic olivine basalt on Miocene (?) sand, etc. (5654). Comparable with rock at Locs. 61 (c), 64–70.

69. Waipiata Road. One mile south-south-west of railway station. (B.) Massive flow as at Loc. 61 (c), 64–70 (5057).

70. Waipiata Road. Three miles south-south-west of railway station. (B.) Massive flow as at Locs. 61 (c), 64–69.

71. Haughton Hill, 50 chains west of Trig. A, Gimmerburn S.D. (B.W.) Massive flow on Miocene (?) sands, etc. Rather coarse-grained almost doleritic olivine basalt probably related to the Waipiata doleritic olivine basalt (308 = P. 3638). See Analysis No. 5.

NOTE.—(a) The tentative suggestion (Benson 1935, fig. 4.B.) that this mass forms part of a flow rising from beneath younger alluvium is now withdrawn.

NOTE.—(b) This is the westernmost mass of Pliocene basalt seen by the writer. McKay's (1884, pp. 65–66) hitherto unconfirmed comments suggest the presence of coeval (or younger?) basalt breaking through Tertiary gravel and lignite in the Upper Manuherikia Valley (near St. Bathans?) about 12 miles further west. Numerous large pebbles of both coarse and finely granular pitted or smooth basalt have been found by J. D. Raeside (priv. com.) during his recent soil-survey of the terrace-gravels on the western side of the Dunstan Range, extending as far south as Cromwell, where Park (1908, pp. 15, 19, 44) has recorded their presence, and along both sides of the Manuherikia Valley as far south as Alexandra and Clyde, where again Park (1906, pp. 46–47) has recorded with petrographic description the presence of olivine basalt pebbles. It would appear probable that flows of basalt, not necessarily of great extent, had recently been stripped off the Dunstan and Raggedy Ranges, unless Park's (1908, p. 34) view be accepted that the pebbles were brought by glaciers from the ranges north and west of Lake Hawea. A small residual patch of basalt separated by a thin layer of sediments from the underlying schist has recently been found by Raeside, near Crawford Hill, on the southern end of the Raggedy Range, six miles east by north of Alexandra. Thus the effects of the Late Tertiary igneous activity in Eastern Otago have extended into Central Otago to a distance of over 70 miles north-west of Dunedin.

72. Swinburn S.D. 100 chains south of Trig. C. (W.) Flow on quartz conglomerate. Olivine basalt (?). No specimen available. See Analysis No. 7.

73. Swinburn S.D. By main road one and a-half miles north-north-east of Trig. I. (T.) Flows on quartz conglomerates. Lower flow coarsely ophitic zeolitised olivine dolerite (5059). Upper flow rather less coarsely granular basanite (5058).

74. Swinburn S.D. Hill west of Pigroot Hut, 94 chains south-east of Trig. L. (W.) Flow on quartz conglomerate. Feldspathic olivine basalt (?). No specimen available. See Analysis No. 8.

75. Swinburn S.D. Beside road immediately west of Round Hill. (H.) Flow (?). Zeolitic basalt (5035). See Fig. 2.

76. Swinburn S.D. The Brothers, near Road. (T.)

(a) Flow resting on sandstone forming summit of South Brother. Finely granular basanite with a little glass (5076).

(b) Horizontally jointed dyke 100 yards west of road. Rather coarsely granular nepheline basanite (5056, 5081).

77. Highlay S.D. (a) Near Trig. H, in north-east corner of the S.D. (B.) One of the highest of several massive flows resting on quartz conglomerate. Feldspar basalt (5754 = P. 5978).

(b) (W.) The erroneously localised specimen noted by Williamson (1939, p. 65) was probably derived from this hill-top, Trig. H. Fine-grained iddingsitic olivine basalt (241 = P. 3636). (See Turner in Williamson, p. 67.) See Analysis No. 9.

78. Green Valley. By road a quarter of a mile north-west of Waihemo School, Waihemo S.D. (T.) Flow resting on greywacke-semi-schist. Medium-grained olivine basalt (5082).

79. Green Valley. On ridge separating upper portion of Green Valley from the Shag Valley, three-quarters of a mile west-south-west of Waihemo School. (B.) Thick flow resting on Duntroonian limestone, Bortonian and basal sandstones on schists. Rather coarse granular olivine feldspar augite basalt (5644). (Cf. 5082 above.)

80. Happy Valley Ridge, three-quarters of a mile north-west of Trig. F, Waihemo S.D., between Happy and Shag Valleys. (B.) Flow resting on limestone, etc., as at Loc. 79. Medium-grained basalt (5650). A little richer in olivine and augite than the otherwise comparable rocks (5082, 5644).

‡88. Kattothyrst. On southern margin of Kakanui S.D. (Br.)* Residual mass of flows totalling 300 feet thick resting on semi-schist. Ankaramite (5746 = P. 3823). Hypocrystalline atlantite (5767 = P. 6039).

89. "Crater" on northern boundary of Waihemo S.D. (Mar.)† Mass of similar thickness of flows on semi-schist.

(a) At Crater, 57 chains at 231° from Trig. C. Zeolitised sanidine bearing nephelinite (5768 = P. 6038).

(b) On track a mile and a half to south-south-west of Crater and one mile E. of Trig. B, Maheno S.D. Feldspar basalt (5769 = P. 6040).

90. Siberia Hill. Trig. C, on south margin of Kakanui S.D. (Mar.) Portion of same group of flows. Anorthoclase-rich biotite atlantite (5766 = P. 6036). Analysis No. 11.

91. Siberia Hill. Beside track 75 chains at 112° from Trig. C. (Mar.) Part of same series of flows. Feldspar basalt (5765 = P. 6005).

92. Trig Island. Beside track 50 chains north of Trig. L, on south margin of Kakanui S.D. (Mar.) Portion of same flow series 300 feet thick in all—olivine augite basalt (5764 = P. 6004).

93. Near Mount Difficulty. Beside track 80 chains west of Trig. D, Kauroo S.D. (Mar.) Portion of same flow series resting on semi-schist as at Locs. 90–92. Olivine augite basalt (5763 = P. 6003).

NOTE.—The writer is greatly indebted to Dr Marwick and Mr Robert Gray, of the Dasher Run, for the collection of specimens from Localities 89–93.

94. Mount Difficulty. Trig. D, in south corner of Kauroo S.D. (B.) Basalt flow residual or plug (?) rising 450 feet above quartz sandstone up to 200 feet thick. Feldspar olivine basalt (5762 = P. 6002). Analysis No. 10.

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* Collector D. A. Brown.

† Collector Dr J. Marwick.

‡ Localities 81–87, 96–99, 101–104; yield older Tertiary volcanic rocks only.

95. Obelisk or Charles Peak. North-west corner of Otepopo S.D. (Mar.) Flow residual or plug rising 75 feet above quartz sandstones 60 feet thick. Olivine augite basalt (5747 = P. 3807).

100. Kauroo Hill. (B.) See Fig. 3. Middle Tertiary dolerite (5719). Late Tertiary doleritic basalt (5738, 5789) and iddingsitic nephelinite (5714–7–8, 5739, 5761, 5770, 5788). Plug of very finely granular atlantite (?) (5737).

(ii) Petrographical Nature and Chemical Composition of the Late Tertiary Igneous Rocks in the Relatively Stable and Moderately Deformed Regions around the Dunedin Central Regions.

Mugearite: Localities 51 and 52. Analysis No. 1. Table V.

This uncommon type of basaltic rock, recently recognised near Dunedin (Benson and Turner, 1940), forms two small, conical hills, rising above a ridge of schist five and a-half miles north-east of Middlemarch. Both phases of mugearite found near Dunedin are represented here. The porphyritic phase (5643, Loc. 52) resulting probably from marginal chilling, is a rather dark grey, finely granular rock without marked fluidal structure, resembles (246), the analysed mugearite from Jeffrey's Hill, Dunedin, and contains rather abundant small ($< 0.6 \times 0.1$ mm.) seriate phenocrysts of andesine (An_{38}) with occasional marginal oligoclase, olivines (< 0.3 mm.) usually elongated parallel to Z and rather decomposed, and octahedra (0.05–0.2 mm.) of magnetite in an extremely fine-grained, feebly trachytic matrix of more or less granular feldspar, prismatic diopside, apatite and dust-like magnetite. The less markedly porphyritic and less finely granular phase (5651, 5652, Loc. 52), an analysis No. 1 of which is here given, is more like the Scottish examples of this rock, especially that from Eigg, both in the more marked flow-structure and the greyish-green colour. (See Harker, 1908, plate vii, fig. 2A.) The seriate phenocrysts ($< 0.2 - 0.3$ mm.) of feldspar are zoned andesine with a core of $An_{45\text{-}42}$, and rarely a little sanidine may be seen mantling them. Olivine (< 0.4 mm.) less altered than the above and similarly elongated, and magnetite octahedra (0.1–0.2 mm.) are also abundant, though the last is not so common in the matrix of this rock as of (5643). Apatite occasionally forms relatively large (0.15×0.05 mm.) prisms. The composition of the rock is very similar both to that of the Dunedin mugearite and of the type rock from Skye, the former of which has been given (Table V, No. 2) for comparison.

Feldspar Basalts: Under this heading are grouped the more feldspathic of the rocks in the Goodwood area described by Service (1934) as feldspar basalts or trachytic feldspar basalts, together with other flows in the Shag Valley and on the Kakanui Range. They are characterised by the predominance of plagioclase both in phenocrysts and in ground-mass, with which minor amounts of phenocrystic olivine, magnetite and titanaugite may or might not be present, and they possess more or less well-marked flow-structure. The plagioclase tabulae are usually not more than 1 mm. long. Their composition varies—about $An_{62\text{-}55}$ for the bulk of the crystals though a narrow

andesine marginal zone An_{40} is sometimes present. Rarely a prism of labradorite has grown around a corroded andesine core. The phenocrysts of the coloured minerals are seldom larger than 0.5 mm. (olivine or augite) or 0.2 mm. (magnetite). The ground-mass texture varies between that of the very finely granular with marked flow structure and dust-like magnetite to less finely granular with a more or less pilotaxitic arrangement. A little sanidine may be detected between the plagioclase laths in most rocks of this group and small flakes of biotite are commonly present, usually near the olivine. Among these rocks may be placed those described by Service from Loc. 37 (2026), Loc. 38 (2016–2020) and Loc. 45 (2025, 2040). One (5754 = P. 5978) among the highest flows on Loc. 77 is very finely granular with marked flow-structure and a little flow-brecciation. It is noteworthy for the presence of irregularly ovoid patches less than 5 mm. in diameter containing very pale brown glass with some marginal subradiating tufts of brown microlitic augite (?). A rock (5769 = P. 6040) similar to this (except for the absence of glass and the presence of biotite), occurs at Loc. 89 (b), and forms that portion of the basalt-cap on the Kakanui Range nearest to Loc. 77, including 5765 (= P. 6005) at the adjacent Loc. 91 and 5762 (= P. 6002, Analysis No. 10*) at Loc. 94, a point a mile beyond the eastern end of the long strip of basalts covering this range.

Basalts of this character occur among the flows analysed by Marshall (1914) forming the North Head of Otago Harbour, their relative abundance there being partly responsible for the difference between the average compositions of the basalts of the Dunedin region and those of the peripheral districts of Eastern Otago already noted.

Basalts containing abundant Phenocrysts of Feldspar, Augite and Olivine: These comprise most of the rocks classed by Service (1934) as feldspar basalts or trachytic basalts, the difference being chiefly in the greater abundance of the coloured phenocrysts, which are, however, never in excess of the plagioclase. As this relative abundance of phenocrysts may depend on the varying factors controlling crystal-sorting prior to eruption, it is not impossible that different portions of the same flow may be grouped in different classes. Among these are rocks from Loc. 37 (2036, 7, 8); Loc. 39 (2021); Loc. 40 (2027–8, 2039); Loc. 45 (2040–1–2); Loc. 46 (2043–4); Loc. 47 (5093); Loc. 48 (5672–4) and (5679 = P. 5988); Loc. 49 (5676 = P. 3824). Probably the material of the so-called "trachytic tuff" of Locs. 46 and 47 is largely composed of weathered and bleached rock-fragments of this character.

Normal Olivine or Olivine-Augite Basalt: Under this heading are grouped basalts of the type most abundant in the region discussed, those with a moderately fine grain-size and more or less well-marked flow-structure containing in varying proportions phenocrysts of olivine and/or titanaugite, with or without relatively subordinate phenocrysts of plagioclase, but without such features suggestive of alkalinity as the presence of sanidine, biotite or zeolites. The occurrence of richly olivinic cognate xenoliths is common among some of

* The presence of phenocrystic olivine in this rock makes it a type transitional into the next division.

these lavas (notably at Locs. 29, 32 and 36), and so also is the presence of more or less digested accidental xenoliths of quartz-schist and quartz showing all stages of reactive absorption. Often the similarity of rocks in several adjacent localities suggests they are portions of a continuous flow. Where this is the case the groups of localities concerned are, in the following list, separated by dashes from those of rocks which were derived from different flows: Loc. 4 (P. 5561); Loc. 10 (5073–4); Loc. 15 (5075); Loc. 16 (5051, 5692, P. 4162); Loc. 17 (5052, 5065, 5079, P. 4165, a flow overlain by an olivine-theralite sill); Loc. 18 (5791 = P. 4149); Loc. 20 (5036); Loc. 24 (P. 5576); Loc. 26 (P. 5578); Loc. 27 (5670); Loc. 27A (5023, 4), —Loc. 28 (5646, with strongly zoned feldspar phenocrysts An_{62-40} and a little biotite),—Loc. 29 (5642), Loc. 30 (5657); Loc. 31 (5656), Loc. 32 (5669), Loc. 33 (5662), Loc. 34 (5655)—; Loc. 36 (5660), Loc. 37 (2037–8), Loc. 43 (5671, 5678), Loc. 44 (2050); Loc. 45 (2041), Loc. 47 (5675, 5677); Loc. 53 (5648); Loc. 54 (5645); Loc. 55 (5658);—Loc. 60 (5665); Loc. 61 (5661, 5668)—; Loc. 62 (P. 3651), Loc. 77? (P. 3636, Analysis No. 9); Loc. 92 (5674 = P. 6004); Loc. 93 (5673 = P. 6003); Loc. 95 (5747 = P. 3807).

The usual minor variations of texture and relative proportions among the phenocrysts and the minerals of the base may be seen among these rocks as well as variations in the manner and degree of alteration. The extent of replacement especially of the olivine by carbonates is noteworthy in some examples.

Normal Basalts with few or no Phenocrysts and medium to rather coarse grain-size: These occur at a few places, including Loc. 25 (P. 5584), Loc. 48 (5672–3,–4,–9), the "olivine dolerite" of Paterson (1941), Loc. 49 (5676), and Loc. 62 (P. 3651).

Coarsely Granular Doleritic Basalts: These include a group of rocks differing from ophitic dolerites in the possession of a granular to sub ophitic texture. The plagioclase (An_{50-60}) forms large (about 1.0 mm.) tabulae and stout laths. The pyroxene is strongly titaniferous and has a large optic axial angle. The olivine is richly forsteritic (Fa_{0-22}), and the iron ore platey ilmenite rather than magnetite. Acicular apatite is abundant. In some rocks a little zeolite is present though insufficient to carry them into the group of teschenites. Variation occurs in the degree to which a porphyritic texture is developed through the presence of phenocrystic olivine and/or titanaugite. The most extensive single flow in Otago, the Waipiata doleritic basalt, is indistinguishable from the Roslyn dolerite of the Dunedin district either on chemical or mineralogical grounds and, like it, is probably less than a hundred feet thick. It originally covered about 90 square miles, and if, as their petrographic features suggest, rocks at Locs. 62 and 71 are outliers of this flow, it may originally have had three times as great an extent. In the following list occurrences which were probably portions of a single flow are placed between dashes as above. Loc. 8? (Marshall, 1918); Loc. 9 (5050); Loc. 14 (5697); Loc. 38 (2014, possibly an outlier of a flow in the north-east of the Dunedin district); Loc. 36 (5664, 5666);—Loc. 40 (2035); Loc. 41 (2034); Loc. 42 (2031,–2,–3); Loc. 45 (2029. 2030), a porphyritic flow with large phenocrysts of augite and rarely

a little zeolite in the ground-mass and vesicles (e.g. 5666); Loc. 47 (5680);—Loc. 61 (P. 3658); Loc. 64 (5663); Loc. 65 (a weathered hand-specimen); Loc. 66 (5055); Loc. 67 (P. 3598 and Analyses Nos. 3 and 4); Loc. 68 (5654); Loc. 69 (5057); Loc. 70 (as 65); Loc. 71 (P. 3638, and analysis No. 5);—Loc. 78 (5082); Loc. 79 (5644 = P. 5983); Loc. 80 (5650), three coarsely porphyritic augite-olivine basalts with a matrix of medium grain-size—; Loc. 100 (5789, iddingsitic). The similarity between the Waipiata and Roslyn doleritic rocks suggests that at least part of the basic rocks in the moderately deformed regions were erupted during the second major phase of the igneous activity in the Dunedin district of which the Roslyn dolerite was a product.

Intersertal Dolerite: A single instance of this rock-type occurs at Loc. 1 (P. 5560). It contains strongly zoned titanaugite ($<$ 1.5 mm.) and subordinate decomposed olivines, largely decomposed rhomboids of ilmenite and tabulae ($< 0.2 \times 0.05$ mm.) of labradorite fraying out into oligoclase (?) microlites diverging into the matrix of partially decomposed pale brown glass in which are slender prisms ($<$ 0.08 mm. long) of basaltic hornblende arranged in parallel groups and associated with minute plates of ilmenite.

Ankaramite: Under this heading are grouped rocks with about 50% of titanaugite in phenocrysts and matrix, together with approximately equal amounts of olivine and labradorite with a little magnetite biotite apatite and deuteric (?) carbonates with or without a little interstitial glass. The more finely granular examples are difficult to distinguish from atlantites in which nepheline occurs in association with plagioclase. Specimens were obtained at Loc. 2 (P. 5596); Loc. 5 (5053, P. 4166); Loc. 14 (5072); Loc. 19 (P. 5597, abnormal in its very minute grain-size, the occurrence of olivine as the only phenocrysts, the presence of picotite and of irregular vesicles filled with aragonite (?) and opal); Loc. 23 (P. 5598); Loc. 24 (P. 5576); Loc. 44 (2045–9); Loc. 57 (P. 3630); and Loc. 88 (5746 = P. 3823). A peculiar variety of ankaramite at Loc. 12 contains seriate phenocrysts of titanaugite ($<$ 1.5 mm.) rarely with a pale greenish core, often grown around and through brown hornblendes (now resorbed with production of magnetite and rhönite (?)), or around iddingsitised olivine, set in a fine-grained, almost panidiomorphic matrix of titanaugite, labradorite, iddingsitic olivine and magnetite.

Zeolitic Dolerites and Doleritic Basalts: The most coarsely granular of these rocks is an ophitic dolerite at Loc. 73 (5059), in which the plates of titanaugite may be as much as 4 mm. long. The radiating zeolite either replaces labradorite with augite or occurs interstitially between the feldspar tabulae. Less coarsely granular is a rather analogous rock (5738) at Loc. 100. Paterson's (1941) "analcite dolerite" (5680) from Loc. 47 is still less coarsely granular, but its abundant interstitial zeolite is not analcite but an aggregate of minute weakly birefringent grains, and the same may be the case in regard to the "teschenite" (P. 5577) of Loc. 25, in which the zeolite not only replaces labradorite, but may form distinct veinlets. Dr Andrew's sample (5682) of the flow capping Table Hill

(Loc. 8), though not containing recognisable nepheline, may be a zeolitic representative of the "doleritic basanite" which Marshall (1918) reports here.

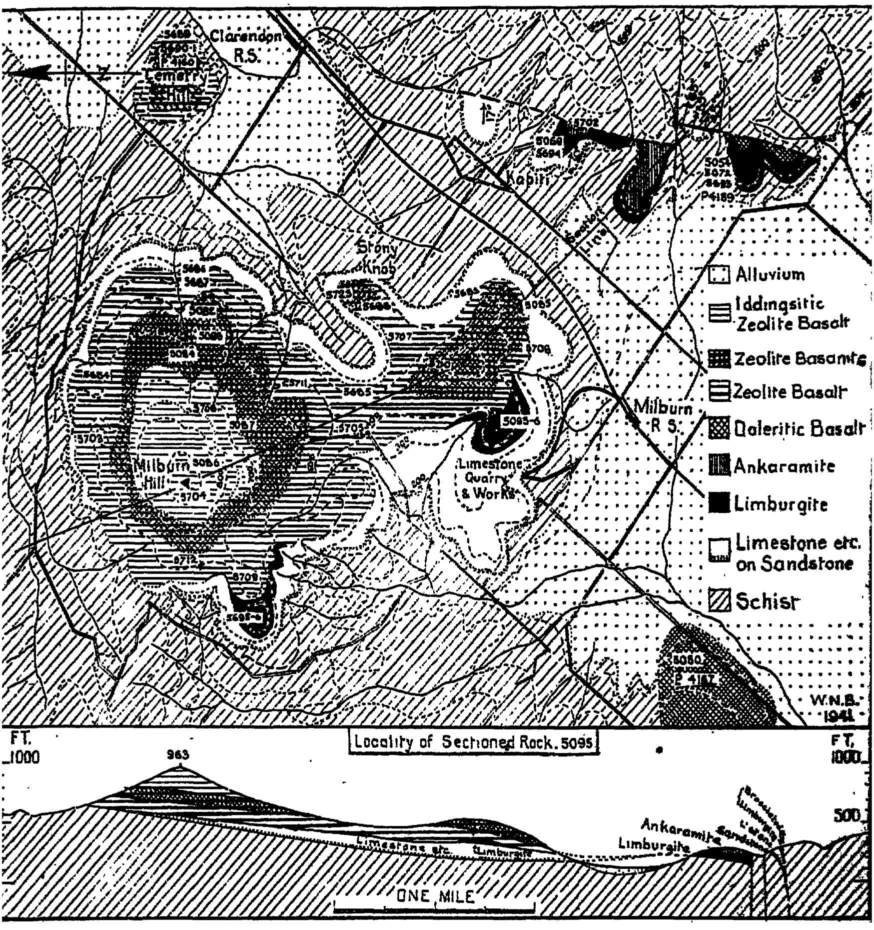

Figure I.

Geological Sketch Map of the Milburn-Clarendon District, showing by numbers the localities of petrographically studied rocks.

Zeolitic Basalts: In this group are placed those basaltic rocks in which, though there is no indication of the former presence of nepheline, there is a considerable amount of scattered zeolite, apparently a primary magmatic constituent and not merely the result of deuteric alterations of feldspars or the filling of vesicles. It is convenient to distinguish between intersertal zeolite basalts in which the characteristic mineral occurs in apparently primary granules between the feldspars and those basalts in which there are irregular veinlets or segregations of zeolite associated with or including crystals of augite larger and more idiomorphic in form than those in the

surrounding ground-mass as if crystallising in a micropegmatoid (see fig. 2)—an association which the writer described in a basalt from New South Wales (Benson, 1915, p. 618). Both modes of occurrence are found in Eastern Otago, though the former is more abundant, especially in the Milburn-Clarendon district, of which a geological sketch map, based on a partial revision of that of Andrew (1906), is hereto supplied. (See fig. 1.) Only general comments may be given here as detailed studies of these zeolite-bearing rocks are being made by Dr Marshall. The basal lava (except where the limburgite occurs), is a finely granular olivine basalt usually without phenocrystic augite and containing but little or no flaky biotite. Acicular apatite is noteworthy, and there is usually present clear intergranular often isotropic zeolite (analcite?). Slides 5085, 5705, 5707–9, 5712 illustrate this type of rock, which may be traced all round Milburn Hill. Occasionally (5703, 5711) zeolites cannot be recognised with certainty. Further, in place of the minutely tabular plagioclase seen in these rocks there may be poikilitic grains of feldspar in which, however, the augite and magnetite grains are as small as those in the ground-mass of the rock (5684,–5,–7,–8,–9), and in a comparable but less zeolitic rock of Cemetery Hill (P. 4160), a little nepheline seems also to be present. Thus with increasing grain-size and content of biotite these rocks become difficult to separate from the overlying zeolitic basanite. The higher parts of Milburn

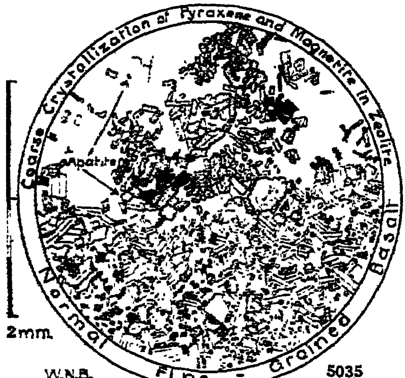

Figure 2.

Margin of a zeolitic segregation containing aggregated and scattered crystals of titanaugite and magnetite larger than those in the groundmass of the enclosing basalt. Slide 5035. Rock from roadside, west of Round Hill, Upper Shag Valley.

Hill, above the basanite are composed of a fine-grained zeolitic iddingsitic basalt (5086, 5704, 5706).* A slightly zeolitic basalt

* Note.—Andrew (1906) found such evidence of transition between the several types of igneous rocks on Milburn Hill that he mapped and described the whole complex as a single unit. During the revision no exposure of weathered interflow surfaces or tuff-beds could be found, but there seems sufficient petrographical evidence to warrant, at least tentatively, the division here suggested, apart from the improbability that so great a thickness (over 300 feet) of lava

occurs at Waihola Hill, Loc. 17 (P. 4164) and at Loc. 27A (5022). That at Loc. 75 (5035) is particularly interesting in the presence in an otherwise normal olivine augite basalt, of large, irregular, ovoid patches of finely crystalline indeterminate zeolite, enclosing abundant small, aggregated prisms and small phenocrysts of titanaugite, octohedra (< 0.2 mm.) of magnetite, a few zoned tabulae of labradorite, and prisms of apatite. Figure 2 illustrates portion of the margin of one of these zeolitic patches about 5×3 mm. in area.

Atlantite or Basanite (sensu lato): Lacroix (1927, p. 20) in 1916 coined the term ankaramite to designate strongly melanocratic basalts in which augite predominated over olivine (in contrast with oceanites in which the reverse relation holds), and remarked that the term ankaramite-basanite might denote the melanocratic rocks in which nepheline was associated with the plagioclase. Lehmann (1924) had, however, introduced the term atlantite for just this purpose, and as it has been found useful in the Dunedin Central area, it will be employed here. The following are brief notes on rocks of this character in the localities listed herein:—

Loc. 2 (P. 5596). A rock on the boundary between normal basanite and atlantite. The phenocrysts of olivine ($<0{\cdot}20$ mm.) are commonly changed to carbonates; those of titanaugite ($< 1{\cdot}0$ mm.) may have corroded green cores. The matrix of minutely prismatic ($< 0{\cdot}1$ mm.) titanaugite, tabular ($< 0{\cdot}1$ mm.) or poikilitic (< 0.4 mm.) labradorite (Ab_{50}), and very subordinate nepheline contains also magnetite, acicular apatite, a little biotite and much secondary carbonate. The rock (P. 4158) at Loc. 3 is less markedly porphyritic, has a less purely crystalline matrix and is much fresher. (See Analysis No. 14.) That of Loc. 6 (P. 4163, Analysis No. 16) is comparable with it, as also is (P. 4143) from Loc. 7, though the last is richer in nepheline showing incipient zeolitisation, and the olivine is almost completely replaced by bowlingite. A more coarsely granular rock at Loc. 8 has been described by Marshall (1918, pp. 63–4) as a doleritic basanite.

Loc. 13 (see Figure 1). A considerable extent of rock of medium grain-size with frequent development of poikilitic labradorite and nepheline, and more or less abundant zeolite forms the middle portion of Milburn Hill, and the mass at Cemetery Hill, Clarendon, described

should consist of a single flow. The basal limburgite is clearly distinct from the zeolitic basalt which overlaps it. The latter shows fairly uniform petrographic characters in the lowest portion of the complex all round Milburn Hill, with the possible exception of the eastern extremity. Doubt arises in the case of other rocks and especially the basal volcanic rock on Cemetery Hill, which show features transitional to the more coarsely granular median zeolitic basanite, and these may actually be the rather finely granular marginal portion of the latter, if the basanite here overlaps the basalt to lie directly on the schists below Cemetery Hill. The petrographical similarity between the median basanite and the iddingsitic zeolitic basalt which caps Milburn Hill is no less marked, but the occurrence on the eastern slopes of the hill of a very finely granular flow-brecciated basaltic rock (5087) affords some indication of the presence of an interflow surface separating these two into more or less independent flow-units.

by Marshall (1912). It is less finely granular than the zeolitic basalt, has abundant small ($\pm$ 0.5 mm.) phenocrysts of titanaugite as well as of olivine (0·5 mm.) and magnetite ($<$ 0·1 mm.) set in a matrix composed of tabular labradorite-andesine, subidiomorphic prisms or irregular grains of nepheline, augite and magnetite with a little flaky biotite and apatite. There are many irregular veinlets or patches of a zeolite with optical properties and twinning resembling those of phillipsite. Examples of this rock are 5082–3–4, 5686, 5710, 5723, and more coarsely granular upper portion of the igneous capping on Cemetery Hill (Loc. 14, 5690–1). The samples partially analysed by Andrew (1906, Nos. 1, 2 and 3*) and by Marshall (1912, B) and that from Cemetery Hill completely analysed by Seelye (Analysis No. 17 herewith, cited through generous permission of Dr. Marshall), may be considered representative of this rock-mass.

At Loc. 17 (5070–1) the flow above the olivine theralite sill is more finely granular and otherwise different from these. The dark minerals are unevenly distributed; a little analcite and thompsonite (?) occurs interstitially, and in irregular micropegmatoidal segregations of granular or poikilitic nepheline and labradorite, in which are minute idiomorphic crystals of titanaugite, apatite and magnetite, with little segregations of sanidine (or anorthoclase) and biotite-flakes.

At Loc. 56 a quarry has been cut in what appears to have been a low dome which displays two very distinct phases of basanitic rock. The lower apparently medium-grained rock (5653) proves under the microscope to be a hyalobasanite in which phenocrysts ($<$ 1.0 mm.) of olivine and of titanaugite ($<$ 0·3 mm.) with prisms (1·0 $\times$ 0·5 mm.) of nepheline and plagioclase (An_{48}) containing innumerable small crystals of titanaugite and magnetite are embedded in a matrix of dark tawny brown glass with similar small grains of the last two minerals locally grouped into a streaked arrangement continuing alike through the glass and the colourless minerals. Under high illumination the glass shows abundant rod-like deep brown crystallites in parallel bundles sometimes radiating from the augite-grains. Carbonates and a little chlorite occur as secondary minerals. This rock passes up into an aphanitic dark grey slightly vesicular rock (5647) with a columnar structure developed on a small scale obliquely to the present land surface. It has some of the features of augitite. The phenocrystic olivine is partly changed to iddingsite, the titanaugite is as before, but no colourless minerals are present save for a little zeolite lining small openings. But because of the greater development of the rod-like brown crystallites, the intervening glass is almost colourless, though patches of dark brown glass remain free of such microlites. A stage in crystallisation following on that reached by (5653) is displayed by (5659) from Loc. 35, a rock the magma of which rose through the fault-plane east of Scratchback Hill and flowed eastwards over the thin layer of Abbotsford Mudstone and sandstone capping the schist. The rock was collected from

* Andrew noted that the powder of these rocks gelatinised on treatment with acid. Marshall noted the presence of nepheline and of the zeolites, the nature of which he is investigating.

the western end of the fault where it forms small oblique to horizontal columns. It is almost holocrystalline with abundant seriate phenocrysts of zoned titanaugite and olivine (0·5 mm.) and magnetite octahedra, the smaller crystals being included in poikilitic more or less idiomorphic crystals or grains of nepheline (0.8 mm. long) are grouped with microlites of labradorite with a little interstitial zeolite. A very little brown glass remains, notably in the centre of a globular aggregate (2·0 mm. in diameter) of small (0·2 mm.) idiomorphic augite prisms surrounded by an outer shell of close-packed augite-granules. The zeolite in the vesicles has some of the features of phillipsite.

At Loc. 58 a rock (193 = P. 3946) previously termed (Turner, in Williamson, 1939, p. 67) a zeolitic olivine basalt has since been found to contain abundant small idiomorphic prisms (0·05 × 0.03 mm.) of nepheline.

A small amount of poikilitic nepheline discovered in rock at Loc. 59 (168 = P. 3936), also once described as a basalt, relates it to the ankaramitic basanites. Seelye (in Williamson, 1939, p. 66) had pointed out that its chemical composition (Analysis No. 12) is very similar to that of the Clarendon zeolitic basanite (Analysis No. 17).

At Loc. 73 the zeolitic dolerite (5059) is covered by a more altered and completely crystalline basanite (5058), in which the bowlingitised olivine seriate phenocrysts of titanaugite and magnetite are wrapped or enclosed by a matrix of coarsely granular (0·5–1·5 mm.) allotriomorphic plagioclase and nepheline in about equal proportions. The very fresh rock (5076) capping The Brothers (Loc. 76) is very like (5659) from Loc. 35, but the horizontally columnar dyke feeding this flow (5056, 5081) is doleritic in its grain-size and in the ophitic form of its deep lilac titanaugite. The tabular plagioclase (0·8 × 0·2 mm.) is a calcic labradorite (An_{68}), and the subidiomorphic nepheline prisms (< 1·0 mm.) contain minute zonally arranged inclusions. Between the colourless minerals is an aggregate of microlites of sanidine (and oligoclase ?) together with chlorite and dusty magnetite as in the olivine theralites of Waihola (Loc. 17).

At Loc. 90 on the Kakanui Range (5766 Analysis No. 11) is a rather special member of this group, noteworthy for the abundance of potassic feldspar, probably anorthoclase rather than sanidine. The olivine phenocrysts (< 1.0 mm.) are richly forsteritic ($Fa_{8\text{-}28}$), the smaller crystals in the ground-mass are more ferruginous ($Fa_{36\text{-}42}$) with marginal zoning. The titanaugites (< 0.4 mm.) have $2V = 52°$ to 56° (+) in the phenocrysts, and $= 40°$ (+) in the tiny ground-mass prisms (0.02 mm.), which are associated with magnetite, and rather abundant flakes of strongly pleochroic biotite occasionally 0.2 mm. wide. These are set in a matrix of poikilitic colourless minerals which tend to form irregularly bounded segregations and comprise nepheline, "anorthoclase" with simple Carlsbad or Baveno twinning and 2V=65° to 68° (—), axial plane perpendicular to (010), and labradorite-andesine $An_{53\text{-}40}$. These optical measurements are due to Dr. F. J. Turner.

At Loc. 88, adjacent to the last described rock, is a more finely granular basanite (5767 = P. 6039) in which prismatic nepheline and tabular labradorite are idiomorphic against the small amount of interstitial brown glass in which are irregular patches of analcite. Besides the normal phenocrysts of olivine and titanaugite there are aggregates of diopside and magnetite surrounded by titanaugite, which may be derived by the resorption of brown amphibole. Finally, it may be noted that what is possibly an exceedingly fine-grained atlantite (5737) forms a plug a mile west of Kauroo Hill (Loc. 100). It contains in vesicles, and irregular plagioclase (and nepheline?) segregations, microlites of alkaline feldspar with a little pyroxene and chlorite recalling the aggregates in the olivine theralites of Waihola. But the rock is too finely granular and altered for exact determination.

Olivine Theralites, the more or less coarsely granular intrusive product of a basanitic magma are well exemplified by the sill at Loc. 17 (5060,-1, 5064, 5067–8, 5698–9, 5700) which will be described elsewhere. The sill appears to exhibit a marked gravitational differentiation ranging from a richly melanocratic basal portion to an upper portion enriched in feldspars and nepheline which has been more or less replaced by a potassic thompsonite. The variation in composition of the plagioclase from the bytownite-labradorite of the lower portion to the andesite of the upper, the increase of potassic feldspar in the higher parts of the sill, the change in average composition of the zoned olivine, strongly forsteritic in the lower portion, increasingly ferruginous not only in the outer zones of any one crystal but in the average composition of the crystals in the higher portions of the sill, and the variation of the composition of the pyroxene during its growth, features made apparent by Dr. F. J. Turner's universal stage measurements, will be discussed in detail.

Olivine Nephelinite: This name approved by the British Nomenclatural Committee and by Tröger (1935) applies to rocks confusingly termed nepheline basalt by Zirkel and Rosenbusch. A good, rather basic example forms a small conical hill at Loc. 50 (5649), Analysis No. 20. The rock is perfectly fresh and contains scanty phenocrysts of olivine (< 0.5 mm.). The matrix consists of faintly pleochroic yellowish to purplish-brown prisms (0.05–0.2 mm. of titanaugite with fluxional arrangement, subidiomorphic grains of nepheline (0.05–0.10 mm.), magnetite (0.005–0.05 mm.), and short needles of a brownish apatite in some of the nepheline grains. No feldspar could be detected in the slide.

Very little or no feldspar could be detected in the olivine nephelinites of Kauroo Hill (Loc. 100). Their peculiar mode of occurrence is described in an appended note. (See also Fig. 3.)

The rock (5714, 5717, 5718, 5739, 5761, 5770, 5788) occurs with either fresh or slightly bowlingitic olivines or showing extensive change to iddingsite. The olivine forms the dominant phenocrysts more or less corroded and in all sizes up to 2 mm. in length. Rarely a little picotite is present, apparently xenocrystic and derived from a scattered and partially resorbed olivine nodule. Phenocrysts of titanaugite are less abundant and smaller (< 0.5 mm.) but rarely

larger ($<$ 3 mm.) crystals occur containing numerous small inclusions of olivine and large magnetites. The ground-mass consists essentially of short ($\pm$ 0.03 mm.) prisms of titanaugite, with small octahedra of magnetite and rather less abundant olivine grains, set in interstitial minutely granular or poikilitic nepheline which may extend in optical continuity for a millimetre, including many small augites, etc. There is often a partial replacement of nepheline by analcite or a birefringent zeolite. Sometimes a zonal extinction in such a zeolite may simulate or be simulated by a small fragment of untwinned plagioclase, but only very rarely can thin idiomorphic tabulae of lamellar plagioclase be recognised in association with the nepheline. Very small, thin apatite needles are abundant in the nepheline. Rarely a little finely flaky biotite is recognisable. Deuteric carbonates are present in some slides.

What may be a zeolitised and otherwise abnormal variety of olivine nephelinite (5768 = P. 6038) occurs at Loc. 89 on the Kakanui Range. Its olivine phenocrysts (1.0 mm.) and sparse, elongated prisms ($<$ 0.3 mm.) of titanaugite are enclosed in a ground-mass of minutely granular titanaugite and magnetite, with a very little biotite inset in a colourless matrix containing some sanidine and some almost uniaxial optically negative grains, probably of the same mineral, though possibly nepheline where the refractive index is not noticeably different from 1.540. There is much indeterminable, probably zeolitic, material less refractive than sanidine which may replace nepheline. The grain-size is too minute to permit exact microscopic determination.

Limburgite in Eastern Otago is so far known only in the Milburn District, where it was collected by A. R. Andrew, though not described in his paper of 1906. The rock lies directly on the limestone or overlaps from it on to the schist. In hand-specimen it is obviously vitreous and breaks easily into many fragments with a sub-conchoidal fracture. Its small vesicles contain zeolite. The rock consists chiefly of a glass which is pale brown in very thin section, with a refractive index determined by Dr Hutton as R.I. (5054) = 1.550–1, R.I. (5760) = 1.549, which corresponds with a silica content of about 53% according to George's (1924) investigations, a figure suggesting that, by the separation of the mafic silicates and magnetite, the residual glass has become richly felspathic. In the glass are innumerable idiomorphic seriate prisms of almost colourless augite up to 0.2 mm. long, octahedra of magnetite rarely reaching 0.1 mm. and olivine subordinate in amount to the pyroxene though larger in grain-size ($<$ 1.0 mm.) either fresh or replaced by iddingsite. Cloudy dark brown aggregates of crystallites are common in the glass especially where the rock shows a rather more advanced crystallisation, though patches of it appear to have been changed to a paler yellow palagonite (?) with minute spherulitic structures. The distribution of the rock is illustrated in Fig. 1. The samples microscopically examined were Loc. 11 (P. 4139, see Analysis No. 22, 5054, 5072, 5693); Loc. 12 (5069, 5694), Loc. 13 (5095-6).

Fragmental Rocks: Comparatively little petrographical study has been made of the basaltic breccias and agglomerates. Coarse basaltic agglomerate and tuff making the two small hills at Loc. 22

(5715) probably formed part of a lenticular mass about a mile in length and nearly 300 feet thick, roughly stratified and now dipping S.E. at 30°. It contains many large or small angular blocks of schist as well as small fragments of a variety of basalts set in a matrix of rather fine-grained basaltic tuff. Agglomerate composed of fragments of vesicular basalts are exposed beneath the massive basalts on the eastern side of Yellow Rock Hill (Loc. 29), and Mount Trotter (Loc. 41), interbasaltic agglomerates have been described (Service, 1934) in Mt. Royal (Loc. 45), and the material in the adjacent Locs. 46 and 47 described as trachytic is better considered as derived from a richly feldspathic basalt magma. A dyke of vitric basaltic breccia (5681) occurs at Loc. 43. Very massive and extensive bedded tuffs and agglomerates associated with the basaltic flows near the head of the Shag Valley between Locs. 74 and 75 may indicate the proximity of an important explosive vent.

List of Analyses (all by F. T. Seelye, except where otherwise indicated).

1.—Mugearite.—Slightly porphyritic (5652). Hill half mile south of Smooth Cone, 5 miles N.E. of Middlemarch, Strath Taieri S.D.

2.—Mugearite.—Porphyritic type (246). Quarter mile N.W. of Jeffrey's Hill Trig. C, Dunedin and E. Taieri S.D. (In Benson and Turner, 1940, p. 193.)

3.—Doleritic Olivine Basalt.*—(Or otherwise dolerite.) North slope of Flat Cap Trig. L, Section I, Block 16, Maniototo S.D. (In Ferrar, 1929, p. 27.)

4.—Doleritic Olivine Basalt.—Flat Cap Trig L* (? P. 3598). Maniototo-Rock and Pillar S.D. (In Williamson, 1939, p. 65.)

5.—Doleritic Olivine Basalt.—(Probably P. 3598.*) 50 chains W. of Trig. A on Haughton Hill, Gimmerburn S.D. (In Williamson loc. cit.)

6.—Doleritic Olivine Basalt.—(42) Farley Street, Dunedin.

7.—Olivine Basalt.*—100 chains S. of Trig. C, Swinburn S.D.

8.—Feldspathic Olivine Basalt.* (?)—Hill W. of Pigroot Hut, 94 chains S.E. of Trig. L, Swinburn S.D. (In Williamson, 1939, loc. cit.)

9.—Feldspathic Iddingsitic Basalt.—Transitional towards basanite (?) (241 = P. 3636). Probably near Trig. H, Highlay S.D. (not Swinburn S.D., as in Williamson, loc. cit.)

10.—Feldspathic Olivine Basalt.*—(Probably 5672 = P. 6002), Mt. Difficulty Trig. D, Kauroo S.D.

11.—Biotite Atlantite.—Rich in Anorthoclase (5766), 15 chains S. of Siberia Hill, Trig. C, Kakanui S.D.

12.—Atlantite.—(168 = P. 3936) Donaldson's Coal Pit, 60 chains N.W. Trig. G, Rock and Pillar S.D. (In Williamson, loc. cit.)

13.—Atlantite.—Rungwe, N. Nyassaland, E. Africa. Anal. ? In Lehmann, 1924, cited by Tröger, 1935, p. 240.

14.—Zeolitised Atlantite.—(P. 4158) Cook's Head, Tokomariro Beach, Akatore S.D.

15.—Zeolitised Atlantite.*—72 chains W.S.W. of Trig. O, Swinburn S.D. (In Williamson, loc. cit.)

16.—Zeolitised Atlantite.—With abundant carbonates (5048 = P. 4163). Head of Noble Creek, quarter mile S. Trig. V, Akatore S.D.

17.—Zeolitised Basanite.*—(Probably comparable with 5689), Cemetery Hill, Clarendon, Waihola S.D.

18.—Olivine Theralite.—(5061) Upper portion of Sill, Lake Waihola.

19.—Olivine Theralite.—(5067) Lower Middle portion of Sill, Lake Waihola.

20.—Olivine Nephelinite.—(5649) Small Conical Hill, 3 miles E. of Middlemarch, Strath Taieri S.D.

21. Olivine Nephelinite.—Adenau, Hohe Eifel. L. Koch. anal. (In Tröger, 1935, p. 257.)

22.—Limburgite.—(P. 4139) On limestone a mile south-east of Milburn Railway Station.

* No specimen of the analysed rock available for microscopic examination.

TABLE V.

Analysis of Late Tertiary Basic Igneous Rocks of East Otago and Comparable Rocks.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
SiO_2	47.69	48.34	46.92	45.85	45.88	45.77	45.83	46.75	44.04	44.38	43.03	41.29	42.96	43.21	42.06	40.83	41.26	43.14	40.50	40.95	40.01	40.86
Al_2O_3	17.74	16.14	14.08	13.27	13.86	12.98	14.35	16.17	15.98	14.90	13.82	13.39	14.95	14.32	14.01	11.59	13.78	17.77	14.89	14.62	14.13	13.20
Fe_2O_3	4.74	3.43	6.80	5.06	1.95	3.17	1.71	2.50	2.99	2.82	3.70	4.21	6.24	2.38	8.58	3.19	4.20	2.88	3.14	4.87	4.57	6.24
FeO	8.47	9.80	5.91	7.18	9.76	8.66	10.76	9.26	9.47	8.85	8.95	9.73	7.58	8.88	5.14	7.63	10.04	7.90	8.24	8.58	6.04	9.18
MgO	3.15	3.16	7.73	9.19	8.55	11.00	9.47	5.25	6.53	8.32	8.59	5.60	7.68	8.35	4.36	10.06	6.78	3.52	5.27	8.51	11.18	5.80
CaO	5.85	6.54	10.22	11.04	10.33	9.07	9.29	8.51	9.12	10.69	9.23	9.47	11.77	10.06	9.48	10.68	9.16	9.51	13.14	11.60	12.07	7.69
Na_2O	5.31	5.24	2.93	2.53	2.76	2.33	2.55	3.91	3.42	3.48	3.91	5.42	3.65	3.64	3.82	3.18	5.48	6.24	3.96	4.10	3.27	2.77
K_2O	2.12	2.01	0.61	0.78	0.80	0.83	0.68	1.50	1.40	1.26	2.14	2.10	1.43	1.63	1.31	1.50	1.91	2.10	2.04	1.55	1.11	2.00
H_2O+	1.82	0.77	0.74	1.02	0.42	0.98	0.98	1.58	0.77	0.77	2.37	0.95	0.57	1.83	2.98	1.98	1.47	2.89	2.95	1.84	2.96	4.34
H_2O-	0.34	0.30	0.80	0.88	0.64	1.40	2.46	0.48	1.67	0.70	0.78	0.90	0.28	1.17	2.30	1.38	0.58	0.88	0.90	0.66	0.52	1.92
CO_2	0.03	0.17	0.58	0.78	2.87	0.10	0.04	0.36	0.08	0.44	tr.	2.43	—	0.08	1.12	5.00	abs.	tr.	tr.	0.04	0.66	tr.
TiO_2	1.08	2.20	2.11	1.94	1.58	2.05	1.62	2.56	3.04	2.54	2.66	2.73	2.10	3.06	2.95	1.88	3.72	2.04	2.52	1.42	2.18	3.96
P_2O_5	1.19	1.50	0.33	0.36	0.30	0.40	0.17	0.65	0.57	0.60	0.73	1.05	1.00	0.61	0.85	0.93	1.41	1.22	2.24	1.26	0.66	1.56
ZrO_2	nt. fd.	0.01	—	—	—	nt. fd.	—	—	—	nt. fd.	nt. fd.	—	—	abs.	—	—	—	nt. fd.	nt. fd.	nt. fd.	—	—
MnO	0.19	0.23	0.19	0.18	0.17	0.20	0.18	0.20	0.20	0.19	0.21	0.29	—	0.19	0.22	0.20	0.21	0.15	0.16	0.21	0.19	0.19
NiO	nt. fd.	nt.fd.	—	—	0.04	0.04	—	—	0.02	0.03	0.01	0.03	—	0.02	—	0.03	—	tr.	0.01	0.02	—	0.01
BaO	0.08	0.06	0.06	0.04	0.08	0.02	0.02	0.06	0.04	0.03	0.06	0.10	—	0.03	0.06	0.05	0.07	0.09	0.08	0.09	—	0.08
SrO	0.015	0.06	—	0.02	0.03	0.04	0.02	0.02	0.03	0.11	0.08	0.04	—	0.05	0.03	0.09	—	0.04	0.05	0.03	—	0.07
Cr_2O_3	nt. fd.	nt.fd.	0.05	0.07	0.05	0.07	0.06	0.02	0.02	0.05	0.04	0.03	—	0.03	0.03	0.06	abs.	nt. fd.	nt. fd.	0.03	—	tr.
V_2O_3	tr.	tr.	—	—	—	0.03	—	—	—	0.04	tr.	—	—	—	—	—	—	0.03	0.05	0.03	—	0.025
Cl	0.02	0.11	—	—	tr.	0.01	abs.	tr.	tr.	0.02	tr.	0.12	—	—	—	—	0.11	tr.	tr.	0.09	—	0.12
F	—	0.05	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0.10	0.15	—	—	—
S	0.02	0.04	0.03	tr.	0.04	0.02	0.05	0.05	0.02	0.05	0.04	0.12	—	0.06	tr.	0.08	0.04	0.07	0.04	0.05	0.28*	0.04
	99.85	100.16	100.24	100.19	100.01	99.77	100.24	100.20	99.96	100.27	100.35	100.00	100.21	100.09	100.20	100.24	100.12	100.07	100.33	100.05	99.83	100.06
Less												.03		.02		.03		.07	.08	.02		.03
	99.85	100.16	100.24	100.19	100.01	99.77	100.24	100.20	99.96	100.27	100.35	99.97	100.21	100.07	100.20	100.21	100.12	100.00	100.25	100.08	99.83	100.03

* SO_3

(iii) Appendix.

Note on the Geology of Kauroo Hill.

Kauroo Hill (Loc. 100 on Plate 36 of Part I of this series) lies twelve miles due west of Oamaru, from the higher portions of which it may be seen standing out prominently in front of the Kakanui Range. The only reference to it in the geological literature appears to be McKay's (1894, p. 31) comment that " its southern base is formed of Palaeozoic rocks, and the higher portions of volcanic rocks covering the edges of the denuded quartz-grits, which make rapidly to the north-west, north and north-east, and cover a considerable extent of country between the Kauroo Creek and the Kakanui River." Actually the structure of this hill is much more complex and interesting. (See Fig. 3.)

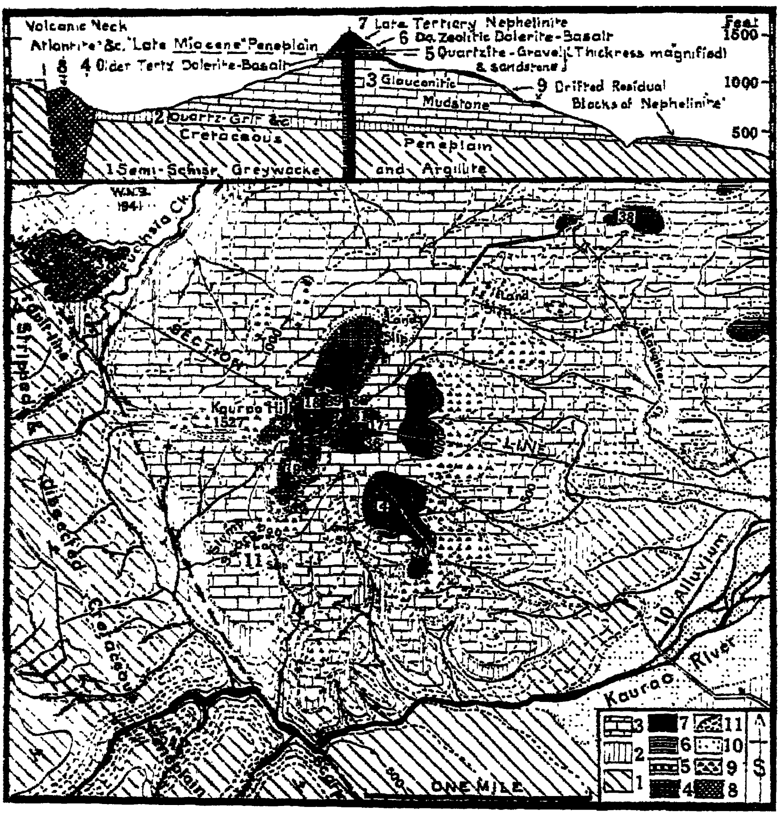

FIGURE 3.

Geological Map of Kauroo Hill, showing by numbers the localities of petrographically studied rocks. (For legend see section above.)

As may be inferred from other comments by McKay (*loc. cit.*), and as Cotton (1917, Fig. 2, Plate xxxi; 1922, Figs. 147, 152) has illustrated, the north-eastern slope of the Kakanui Range is an almost completely stripped portion of the Cretaceous peneplain passing downwards beneath its covering sediments in the broad valley of the Kakanui River. On the higher portions of the range are residual masses of Late Tertiary basic lavas either resting directly on the greywackes and argillites which are exposed on the Cretaceous peneplain or are separated therefrom by a small thickness of quartz-grits, the upper surface of which marks the local level of the " Miocene "* peneplain. (See Part I, Fig. 2, Section X—X, and notes on Locs. 89–95 given above). On the lower portion of the slopes of the range a residual mass of the covering strata capped by a doleritic basalt forms a mesa (Cotton, 1922, Fig. 152) termed Government Hill (Loc. 87), which differs from the above-mentioned lava-capped residuals in that its igneous cover has all the petrographic features which distinguish the usually sheet-forming pre-Miocene basic igneous rocks of Oamaru, Mount Charles and Moeraki from the more alkaline late Tertiary lavas herein described. The features of the older rocks have been briefly noted by Hutton (1889) and Marshall (1925), and will be discussed in detail elsewhere. Kauroo Hill, so far as is known at present, is unique in Eastern Otago in that basic igneous rocks of both Older and Later Tertiary age occur in close association separated by the trace of the " Miocene " peneplain.

The Cretaceous peneplain, sloping down from the summit of the Kakanui Range, is broken by a fault which forms the tectonic boundary of the Kakanui Valley adjacent to Kauroo Hill, the region beneath that valley and hill having been thrown down some 200–300 feet. The downthrown surface of the peneplain is for the most part concealed beneath Kauroo Hill, but on either side thereof the removal of the sediments covering the peneplain has brought into striking relief a fault-line scarp through which emerge the gorges of the superposed valleys of Kauroo River and Fuchsia Creek.

Resting on the peneplain beneath Kauroo Hill is a layer of quartz-grit about 50 feet thick and well cemented on the eastern side of the hill, but over twice as thick, feebly cemented or even friable on the north-western. This is probably the equivalent of the Limonitic Sandstone of von Haast (1877) and McKay (1887) and the Herbert Series of Brown (1938). It is followed by glauconitic mudstone. Where the contact of these two formations is exposed (at the point where the line of section of Fig. 3 crosses the little valley at the eastern foot of Kauroo Hill), the glauconitic mudstone appears to rest disconformably on the sandstone and its basal layer contains rolled pebbles of quartz up to two centimetres in diameter. Higher up, a layer of white weathered silt-stone and mudstone (exposed on the eastern side of Slaughter Creek) seems to be without trace of glauconite, though interbedded in the glauconitic mudstone, which, as a whole, may correspond with the Lower Greensand of McKay and the Otepopo Series of Brown. It is almost indistinguishable

* See footnote on p. 85.

from the Abbotsford Mudstone of the Dunedin District, and, like it, exceedingly prone to land-slip movements. About 600 feet thick of this mudstone occurs below a sheet of dolerite-basalt, approximately 50 feet thick, forming the flat-topped northern and southern spurs of Kauroo Hill. This rock (5719) has the petrographic characteristics of the Older Tertiary dolerite-basalts as distinct from those displayed in the Late Tertiary basic lavas of comparable grain-size. The concealment of the lower margin of this sheet by creeping soil prevents decision as to its intrusive or effusive character, though the probability of the former is suggested by comparison with similar rock-masses near Moeraki.

The cap of Kauroo Hill is a steep cone rising about 280 feet above the surface of the doleritic basalt. It consists chiefly of fine-grained occasionally vesicular iddingsitic nephelinite (5718, 5739) resting on a thin flow of slightly zeolitic doleritic feldspar-olivine basalt (5788). Both of these are described above, and are clearly comparable with Late Tertiary lavas. The lower flow is separated from the underlying dolerite by not more than a few feet thick of coarse quartzite gravel and brown chloritic sandstone, which is exposed on the north, east and south sides of the peak. The boulders seem to have been derived from locally silicified portions of the quartz-grits, such as rest on the Cretaceous peneplain on the upper parts of the Kakanui Range, and may be supposed to have been deposited as flood-plain gravels when the older dolerite was laid bare during the formation of the so-called " Late Miocene " peneplain, and may mark the approximate level of that peneplain in the neighbourhood of Kauroo Hill, namely about 650 feet above the Cretaceous peneplain. If that be so, the angle of inclination between the two peneplains is here rather less than four degrees.

The Late Tertiary lavas in the vicinity of the peak comprise not only the two masses mentioned, but also an extension of the zeolitic dolerite-basalt capping the hills to the east-north-east of Kauroo Hill (5738), and a mass of iddingsitic nephelinite forming the eastern buttress of the peak (5717, 5736, 5761, 5788), and thinner but still massive outliers extending nearly a mile further to the east and south-east (5714, 5740, 5770). The localities whence the several described specimens were collected are denoted by the two last digits of the corresponding specimen-numbers on the map (Fig. 3). The steeper slopes beyond these massive outliers are littered by drifted residual blocks of nephelinite.

The fact that the outlying masses of Late Tertiary lava rest *in situ* on the glauconitic mudstone two or three hundred feet below the assumed level of the Tertiary peneplain may have one of two possible explanations. The more probable hypothesis assumes that following a small uplift of the Tertiary peneplain, occurring before the Late Tertiary eruption had broken out, the older dolerite became the cap of a mesa rising above the surface which was quickly eroded out of the very weak surrounding mudstone. The Late Tertiary lava either broke through the older dolerite and flowed over its edge on to the surface of the surrounding mudstone (as indicated in Fig. 3), or, having been erupted from a vent at the eastern side of the

dolerite-capped mesa, accumulated against its flank until it flooded over its upper surface. The overlapping of an eroded scarp of Caversham sandstone by the early basaltic lavas at St. Clair may be recalled in this connection. (See Part I of this series, fig. 1.) The second variant of the hypothesis seems, however, on topographic grounds, to be less acceptable than the first, which is not without its difficulties. An alternative hypothesis holds that the Late Tertiary lavas on Kauroo Hill was derived from the vent adjacent to the fault-line on the western side of Fuchsia Creek, and flowed eastward on the Miocene peneplain covering and extending beyond the mass of older dolerite. Later, when uplift and erosion had allowed the excavation of the valleys of the Kauroo River and Fuchsia Creek, extensive mass-movements in the glauconitic mudstone resulted in the downward slumping of mudstones and their lava cover on the eastern side of Kauroo Hill. The margin of the older dolerite on this side is, on this view, a slump-scarp comparable with that occurring on the north-eastern face of Swampy Hill, near Dunedin (see Benson, 1940, fig. 5), except that a remnant of the subsided portion of the nephelinite remains tilted against this scarp to form the eastern buttress. This explanation, however, is difficult to reconcile with the formation of the valley of Fuchsia Creek in its present position, and cannot yet be supported on petrographic grounds, since the only specimen obtained from the Fuchsia Creek volcanic vent differs from any microscopically examined lava on or east of Kauroo Hill, in that it is apparently atlantitic in composition (5737). So far, however, only a very hasty examination of the Fuchsia Creek vent has been made, and further study would be desirable.

Whichever (if either) of these hypotheses be true, it seems clear that uplift following the Late Cainozoic eruptions caused the rejuvenation of the valleys draining the area, and the formation of the steeper lower slopes of Kauroo Hill down which have drifted masses of residual boulders, chiefly of nephelinite, accumulations of which cap and protect the lower spurs of the main hill. It also made possible the removal of the covering strata from the Cretaceous peneplain west of Kauroo Hill, and the superposition on to and incision into that surface of the streams which originated as consequent streams on the tilted surface of the Late Tertiary peneplain when the Kakanui Range was being lifted up to its present elevation.

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Current Views on the Origin and Tectonic Significance of Schistosity.

By FRANCIS J. TURNER, University of Otago.

[*Read before the Otago Branch, October 14, 1941; received by the Editor, October 17, 1941; issued separately, September, 1942.*]

INTRODUCTION.

CURRENT views on schistosity cannot be summarised without discussion of older hypotheses embodied in classical papers, selected examples of which are therefore cited. The number of recent publications containing statements that bear upon the subject is so large that only a limited number dealing with the more important aspects of the subject are referred to. Discussion is confined to the following topics:—

(a) Definition and nature of schistosity.

(b) Processes contributing to the development of schistosity.

(c) Relation of schistosity to deforming movements and forces.

DEFINITION AND NATURE OF SCHISTOSITY.

There is considerable confusion in the prevalent usage of terms such as *schistosity, foliation, flow cleavage, fracture cleavage,* etc., and much of this confusion arises from employing genetic terms (e.g., flow cleavage) for structures whose origin cannot usually be demonstrated with certainty from ordinary field data and petrographic observations. Sander (1930, pp. 97, 98, 99) recommends the employment of a purely descriptive non-genetic term to cover the parallel fabrics of metamorphic rocks; he includes all such structures ("sets of planes of mechanical inhomogeneity") in his term "*s*-surfaces" ("*s*-planes"). The present writer (Turner, 1936, pp. 202, 203) has defined schistosity, as far as possible in non-genetic terms, to denote "the property by virtue of which rocks cleave along surfaces (not necessarily plane) determined by crystallisation or mechanical deformation of the rock-forming material under the influence of stress or high temperature." This includes only metamorphic structures (or pre-metamorphic structures accentuated by metamorphism) and excludes parallel fabrics developed by flow in partially molten masses.

It is emphasised at the outset that schistosity may originate in more than one way, and that observations in the field, on the hand-specimen and with ordinary petrographic methods are frequently insufficient to diagnose the mode of origin for any particular case. It is here that the results of fabric analysis, interpreted kinematically in conjunction with the other structural data, are of greatest assistance.

The structural features that *may* be associated with schistosity are summarised briefly thus:—

(1) The most obvious and widely developed character of schistose rocks is a tendency for platy or prismatic crystals of minerals such as micas, chlorites, amphiboles and epidotes to show dimensional parallelism.

(2) There is also a tendency in most schistose rocks for crystal cleavages to lie parallel to the schistosity (as in micas and chlorites) or to a line in the schistosity (as in amphiboles). C. K. Leith (1913, pp. 78, 79) discusses this point and concludes that " the dimensional parallelism of mineral particles is the controlling factor in rock cleavage; (and) that to this control is due the mutual parallelism of mineral cleavages of mica or hornblende cleavages." [This conclusion must be modified in the light of petrofabric evidence—see below under (4).]

(3) J. Tyndall (1856, pp. 44, 45) experimentally produced perfect cleavage in wax by subjecting it to pressure, and concluded from this that schistosity is independent of preferred dimensional orientation of the mineral grains. [Sorby (1856), however, considered that parallelism of acicular crystals of wax was responsible for the cleavage produced by Tyndall.] This brings out a further possibility, namely, that schistosity may sometimes be determined not so much by the presence of dimensionally parallel crystals as by the development of planes of mechanical weakness during deformation. According to G. F. Becker's theory schistosity (or slaty cleavage) " is due to a weakening of cohesion along planes of maximum tangential strain " developed during deformation (Becker, 1904, p. 11). He further implied that the cohesion referred to was at least partly intermolecular (*loc. cit.*, p. 22). Daubrée from experimental work on the production of schistosity had come to similar conclusions many years previously.

(4) Sander has shown that in almost all schistose rocks there is a greater or less degree of preferred *crystallographic* orientation of the component mineral grains, even for minerals such as quartz, calcite or feldspar which usually occur in equidimensional grains and therefore lack *dimensional* orientation. Orientation of grains according to the space-lattice structure would thus appear to be more important than orientation according to crystal form.

(5) Schistose rocks frequently cleave along surfaces of rupture. The term *fracture cleavage* was used by Leith to cover such structures (e.g. Leith, 1913, pp. 61-64) which have been termed *false cleavage*, *strain-slip cleavage*, etc., by various other writers (cf. Harker, 1932, pp. 157, 158). Such surfaces of rupture may originate in more than one way and may later be modified or intensified by post-tectonic crystallisation of new mineral grains. In this modified state they may be indistinguishable from schistosity of the type described by Leith as *flow cleavage* (i.e. schistosity resulting from plastic flow of solid rock). It has been stated (e.g. Swanson, 1941, pp. 1247, 1252) that rocks with " flow cleavage " can part along *any* plane parallel to the schistosity, whereas " fracture cleavage " can occur only upon a limited number of surfaces of mechanical weakness (slip- or rupture-surfaces). In the writer's opinion this distinction is invalid. Even

when preferred orientation is strong, crystallographic parallelism of the component grains is merely approached, and so any one surface of " flow cleavage " is determined in detail by the size, shape, orientation, and mechanical properties of the crystals (usually of several minerals) encountered. In a coarse rock with preferred orientation of a low order, the planes of " flow cleavage " may be more widely spaced than the " fracture cleavage " surfaces of a fine slate.

(6) When schistosity has developed during metamorphism at high temperatures, or when crystallisation accompanying low-grade metamorphism has been sufficiently prolonged, a laminated structure [*foliation*, according to the usage of Harker (1932, p. 203)] involving concentration of particular mineral assemblages in alternating layers parallel to the schistosity has commonly been produced as a result of metamorphic differentiation. On the other hand this is far from being a universal feature of schists of low metamorphic grade even when schistosity is very perfectly developed. The origin of this laminated condition and its relation to schistosity and bedding have recently been discussed by the writer (Turner, 1941). The writer does not agree with the statement of Swanson (1941, p. 1246) that laminated structure of this sort is typically absent from rocks having " flow cleavage."

SCHISTOSITY AS A PRODUCT OF MECHANICAL AND CRYSTALLOBLASTIC PROCESSES.

The processes concerned in development of schistosity have been classed in three groups (cf. Grubenmann and Niggli, 1924, pp. 234, 235; Tyrrell, 1930, pp. 303, 304) :—

(a) *Cataclastic* (rupture, rotation and differential movement of rock components).

(b) *Plastic* (deformation and flow of crystals or rocks without destruction of their continuity).

(c) *Crystalloblastic* (growth of crystals).

The first two groups are essentially mechanical (kinematic) processes, while crystalloblastic growth of crystals by contrast is of a chemical nature. E. B. Knopf (1931, p. 17) has suggested on this basis that the terms *cataclastic* and *crystalloblastic cleavage* (i.e., schistosity) might prove useful in distinguishing between parallel fabrics dominated by mechanical processes and crystalloblastic growth respectively.

Chemical reconstitution and recrystallisation of the rock-forming minerals, when active, will play an important part in determining the nature of the ultimate fabric of the rock. Sander (1930, pp. 262, 263; Knopf, 1933, pp. 460-462) recognises three possibilities as to the relation between crystallisation and deformation.

(a) Mechanical deformation alone; any recognisable crystallisation is *pretectonic* (*prekinematic*).

(b) Mechanical deformation, accompanied (and assisted) by growth of crystals; crystallisation is *paratectonic (parakinematic)*.

(c) Mechanical deformation, followed by growth of crystals; crystallisation is *post-tectonic (postkinematic)*.

Sander draws attention to the difficulty of distinguishing between fabrics resulting from paratectonic crystallisation that has continued slightly after cessation of deformation, and those governed by purely post-tectonic crystallisation. Furthermore the sequence of events in deformational metamorphism may include alternating phases dominated now by mechanical processes, now by crystal growth (cf. Turner, 1940, pp. 188-190). Again deformation may be accomplished largely by recrystallisation alone. It is thus clear that it will be impossible to classify *all* examples of schistosity as either cataclastic or crystalloblastic, even if these terms are used in a broad sense.

While it is recognised that several or all of the processes cited above may take part in a given instance of metamorphism, it is nevertheless helpful to consider each of the schist-forming processes separately and to note the importance attached to each in current theories of schistosity. The aspects considered below are as follows:—

(1) Development of slip-surfaces in rocks during plastic deformation.

(2) Ruptural deformation of rocks in relation to schistosity.

(3) Rotation of rigid grains in a plastically flowing matrix.

(4) Plastic deformation of individual grains.

(5) Rupture of grains.

(6) Paratectonic crystallisation as a factor in rock deformation.

(7) Post-tectonic crystallisation and its effects upon the rock fabric.

Development of Slip-surfaces During Plastic Deformation of a Rock.

The condition necessary for plastic deformation of materials such as rocks which possess a high breaking strength is high confining pressure such as obtains at depths of a few miles within the earth's crust. Such conditions have been artificially reproduced in the laboratory, and an interesting series of investigations upon the plastic deformation of rocks and minerals has been commenced by D. Griggs (1936).

G. F. Becker (1893, 1904, 1907), from a mathematical analysis of stress and strain in a *homogeneous* body subjected to plastic deformation without change in volume, concluded that change in shape of the mass is accomplished by differential slip along two sets of planes of maximum slide, with which he identified the schistosity of naturally deformed rocks. He further correlated the planes of maximum slide with the circular sections of the *strain ellipsoid* (the ellipsoidal form assumed by an initially spherical body during deformation). He showed, too, that whereas differential movement would be active on both sets of slip-surfaces if deformation were brought about by simple compression (as in a vice), it would probably be restricted to one set of slip-surfaces in the much more frequent case of rotational strain (as when a plastic mass on a rigid surface is deformed by an obliquely directed force).*

* The reader unfamiliar with the terminology and principles of deformation is referred to E. S. Hills (1940), pp. 20-43.

Certain details of Becker's theory have been severely criticised: there is obviously a considerable difference between the homogeneous body considered by Becker and the heterogeneous mass which constitutes a rock; further, certain fundamental assumptions made in applying the strain ellipsoid to the case in question have been shown to be incorrect (e.g., Griggs, 1935). Nevertheless Becker's results, arrived at from examination of an ideal simple case, can profitably be applied (though not in a mathematically exact sense) to the complex case of rock deformation. "The most notable feature of Becker's theory is that deformation takes place by slipping of material along planes predetermined by their relation to the stress distribution in the body undergoing strain. This fundamental concept retains its value in spite of the fact that experimental work has indicated that the planes of maximum shearing stress in elastic strain are *not* the planes upon which slip takes place above the elastic yield point." (Knopf, 1933, p. 447).

Sander and Schmidt have reached conclusions that are in general agreement with Becker's thesis from a different line of approach, namely, a kinematic interpretation of the structures of deformed rocks with reference in particular to the orientation of mineral grains by space-lattice structure as revealed by petrofabric analysis. They attach great importance to Becker's views and emphasise the role of slip movements on surfaces of shearing (a type of *s*-surface) which, like Becker, they correlate in many cases with the schistosity of the deformed rock (e.g. Sander, 1930, pp. 97-101, 218-219). In two fundamental respects, however, they differ from Becker:—

(1) According to Sander and Schmidt, schistosity originating parallel to shear-planes, though very important, is not the only type of schistosity commonly occurring in deformed rocks.

(2) When a relatively homogeneous (mechanically isotropic) rock such as a shale is plastically deformed, the slip-planes that develop have a purely mechanical origin, much as pictured by Becker, i.e., the rock yields along surfaces of maximum shearing-stress. Much slaty cleavage transverse to the bedding originates thus. More usually, however, the rock is not originally homogeneous, and prior to deformation already possesses surfaces of weak cohesion such as planes of bedding, flow, foliation or pre-existing schistosity. Under these circumstances slip will tend to occur along the mechanically weak *s*-surfaces already present, rather than on planes of higher shearing-stress for which the strength of the rock is also greater. This is supported by commonly observed (but by no means universal) coincidence between bedding and schistosity.

The writer elsewhere has given a more detailed summary of the views of Becker and of Sander and Schmidt on the relation between schistosity and slip movements accompanying deformation (Turner, 1936, pp. 202, 210).

RUPTURAL DEFORMATION OF ROCKS IN RELATION TO SCHISTOSITY.

At atmospheric pressures rocks and rock-forming minerals are brittle; under increasing stress (e.g., in a simple compression) they deform elastically until the elastic limit is reached, after which they

fail by rupture. Under high confining pressures, however, rocks deform plastically after the elastic limit is exceeded. That is, the shape of the mass is permanently altered without loss of its essential continuity. Nevertheless, plastic deformation of rocks, even under these conditions, will not proceed indefinitely but ultimately ends in rupture (cf. Griggs, 1936). Therefore the generally recognised distinction between zones of fracture and flowage in the earth's crust is valid in only a broad sense, and it must be understood that fracture can be and often is associated with plastic deformation in the zone of rock flow (cf. Sander, 1930, p. 91). " Earlier it was generally assumed that ruptures of any kind would have been formed during a late phase of mountain-building, after plastic deformation, as when the rocks no longer had the same plasticity as during the principal deformation of the orogeny. But according to the results of more recent investigations upon fabric, it appears still more likely that cracks and joints can originate at any time during the mechanical deformation and in conjunction with the crystalloblastic process." Eskola (1939, p. 310).

Local rupturing of individual crystals, though common enough in plastic deformation of rocks, will not be considered here, but only rupture on a larger scale independent of the orientation of the grains concerned and sufficient to affect the continuity of the rock. These fractures are of two kinds, viz., *shear-cracks* and *tension-joints.* Their relation to the fabric of the deformed rock and to the deforming forces has been discussed by Sander (1930, pp. 91-97) Eskola (1939, pp. 308–312) and others. The following essential points may be mentioned here:—

(1) The commonest shear-cracks are those parallel to the tectonic axis of the deforming movement (= *b* axis of the fabric) and hence denoted by the general symbol (*h0l*) with reference to the fabric axes.* These (*h0l*) cracks may be inclined to the prevailing schistosity (*ab*) at any angle, but angles of less than 45° are usual. while in the case of steeply dipping schistosity in fold-mountain ranges (schistosity due to " flattening ") the shear cracks may often be approximately parallel to the schistosity itself (cf. Eskola, 1939, p. 309). When several sets of shear-cracks intersect in *b* the rock tends to split into elongated rod-like fragments parallel to *b* (*pencil structure*). Closely spaced (*h0l*) cracks giving rise to a " fracture cleavage ") that intersects the schistosity (" slaty cleavage ") obliquely have long been recognised as commonly occurring in slates. They have been attributed by many writers (e.g., Leith, 1905; Harker, 1932, pp. 158-159) to superposition of a second deformation upon that responsible for the main schistosity. Becker (1907) on the other hand offered an ingenious explanation for the simultaneous development of (a) schistosity resulting from plastic flow on one set of planes of maximum shearing stress and (b) fracture cleavage originating by rupture on the second set, during deformation in-

* The fabric axes *a* *b* and *c* are three mutually perpendicular lines of reference employed in describing features of a rock fabric. The *c* axis is normal to the plane of most conspicuous schistosity (*ab*), while *b* is the direction of lineation in the schistosity surface. It is parallel to the axis of folds developed simultaneously with schistosity.

volving rotational strain. Modern students of rock fabric (e.g., Sander, 1930, pp. 100–103, and Eskola, 1939, p. 288) attach great importance to Becker's theory.

(2) Tension-cracks genetically connected with schistosity are usually perpendicular both to the schistosity plane (*ab*) and the linear structure (*b*). These *ac* joints (cross-joints or Q-joints) range from microscopic cracks that may be restricted to the more brittle layers (e.g., Sander, 1930, Fig. 104), to large-scale fractures that may give rise to conspicuous surface features such as the rectangular "schist tors" of the schist areas of Central Otago. Sander (1930, p. 219) cites instances when closely spaced *ac* tension-cracks impart to the rock a fissility that can itself be classed as schistosity (cf. also Eskola, 1939, p. 309).

(3) Other sets of fractures than the (*h0l*) and *ac* cracks described above are well-known in schistose rocks and may be due to either tensional or shearing stress. They cannot themselves give rise to a schistose structure and therefore are outside the scope of this paper.

(4) Of widespread occurrence, especially in laminated rocks, is the type of schistosity termed *strain-slip cleavage, fracture cleavage,* etc., which originates by complete or incipient rupture of the rock along closely spaced parallel planes (e.g., see Leith, 1913, pp. 61–64). The evolution of schistosity (*Umfaltungsclivage* of Sander) by small-scale close folding in laminated rocks followed by rupture along the stretched folds was described by Heim in his classic work on the Tessin gneiss of Switzerland, and has recently been discussed in several easily accessible papers by Mrs E. B. Knopf (Knopf, 1931, pp. 14–20; 1935, pp. 204–207; 1938, pp. 189, 190, pl. 19). Elsewhere (Turner, 1936, p. 208) the present writer has summarised the process thus:—

"In markedly anisotropic rocks the slip-planes typically are pre-existing surfaces of weak cohesion such as planes of bedding, flow, foliation or previously developed schistosity, all of which are included by Sander in a single category as *s*-planes. During deformation of a mass consisting or alternating beds [or laminae] of variable competency, slipping along the intervening *s*-planes is often accompanied by development of flexures in the competent beds [or layers]. The incompetent beds simultaneously yield by slipping, giving rise to minor drag-folds which are essentially slip folds (Knopf, 1935). When deformation is complete, the original *s*-planes have been transposed into a new direction (Knopf, 1931, pp. 16–18) but still retain their identity. The schistosity so developed is parallel to the transposed *s*-planes and may be termed 'transposition cleavage' [*Umfaltungsclivage*] in contrast with the 'slaty cleavage' which cuts across the original *s*-planes. . . . Strain-slip cleavage may be regarded as an intermediate stage in the development of 'transposition cleavage' and is therefore a feature of the early stages of deformation of anisotropic bedded rocks. It must be noted, however, that when an initially isotropic shale has acquired schistosity of the 'slaty cleavage' type, it has become markedly anisotropic; further deformation may result in isoclinal folding of the slaty cleavage, giving first strain-slip cleavage and perhaps ultimately a new

schistosity of the ' transposition cleavage ' type. In slaty rocks of initially relatively isotropic character the development of strain-slip cleavage therefore is characteristic of the late stages of deformation, or may indicate repeated metamorphism (Knopf, 1935.)"

ROTATION OF RIGID GRAINS IN A PLASTICALLY FLOWING MATRIX.

In 1853 Sorby, from his early microscopic studies of slate and artificially compressed mixtures of clay and haematite, attributed the observed dimensional parallelism of the mineral flakes to mechanical rotation by which their longest dimensions were brought into a plane (the schistosity or cleavage) perpendicular to the compressing force. The geologists of the Wisconsin School (e.g., Leith and Mead, 1915, pp. 173–176) included mechanical rotation of the original grains and ruptured fragments, together with recrystallisation and growth of new grains, as the main processes concerned in *rock flowage* by which schistosity was presumed to originate. In fact rotation as pictured by Sorby has long been generally accepted as one of the mechanisms by which prismatic and platy minerals may achieve preferred dimensional orientation in metamorphic rocks. It has been discussed from the view-point of fabric analysis by Sander (e.g., 1930, 149–150), Knopf (1938, pp. 133–135) and Eskola (1939, p. 291) who agree that *rigid inequidimensional* components of a rock may become oriented according to their external form during deformation of the rock. Where the components in question are crystals with a pronounced prismatic or tabular crystallographic habit, the resultant preferred orientation will be according to crystal space-lattice as well as external form. Sander (1930, p. 150, Fig. 59) has figured an example of preferred orientation of small, rigid rods (with their long axes in the AB plane of the strain ellipsoid) in plasteline, induced by artificial compression and consequent plastic flow of the heterogeneous mixture. He also records instances where elongated grains of quartz, enclosed by calcite that has flowed plastically during deformation of the rock, have developed preferred orientation with their long axes (= *c* crystal axis) subparallel to the B axis of the fabric, i.e., to the axis of rotation (Sander, 1930, p. 201, D 175, 186).

The following remarks by Mrs Knopf (Knopf, 1938, pp. 134, 135) may be cited in connection with the role of mechanical rotation in contributing to dimensional parallelism of crystals.

"It is possible that this orienting by grain shape has played a larger part in the development of preferred orientation than has hitherto been suspected. . . . Sander has always made a clear distinction between the orienting mechanisms of gliding and those of movement of rigid bodies in response to flow. But he has always stressed the fact that a preferred orientation that is now recognised by the position of the crystal lattice in the grains where there is no orienting by shape may, nevertheless, have been assumed in a stage of seed orienting when the shape of the minute grains determined their position. Later grain growth destroyed the fabric habit of the smaller grains and thus destroyed the evidence of any relation between shape and position, but preserved the preferred orientation of the crystal lattice."

It is probable nevertheless that dimensional orientation of crystals in the AB plane of the strain ellipsoid as a result of mechanical rotation alone would not reach a high degree of perfection unless deformation of the rock concerned was extreme. G. F. Becker (1904, p. 11) long ago considered mathematically the case of preferred orientation induced in mica scales originally oriented at random in an enclosing mass of mud subject to compression. For the scales to attain an average inclination of 2° to a given plane (preferred orientation of a high order) it would be necessary to compress the whole mass until it was reduced to 5½% of the initial thickness.

So far the discussion has concerned only rotation of rigid inequidimensional crystals or aggregates of grains in a plastically deformed matrix. Petrofabric analysis of deformed rocks shows that grains of a given mineral very commonly tend to be oriented, regardless of their shape, with some mechanically significant crystallographic line or pole (e.g., the optic axis in quartz, the pole of 001 in micas, the pole of the rhombohedral twin lamellae in calcite) in a plane perpendicular to a line (the *b* axis) in the fabric of the rock. The corresponding fabric diagram shows a girdle of concentration of the poles in question, with *b* as the girdle axis. Orientation patterns of this type have been explained as resulting in many cases from a complex process of intergranular movement and grain deformation, in which rotation of the individual grains about *b* brings them into a position favouring deformation by such means as intragranular slip. W. Schmidt (1932, pp. 172–175) has discussed this aspect of the case in some detail, and points out that perfect girdle fabrics may develop as a result of deformation involving but slight rotation of grains. Nor is this by any means the only mechanism by which girdle fabrics may originate (cf. Knopf, 1938, 153–155).

According to Schmidt's theory, girdle fabrics with space-lattice orientation controlled in part by rotation of grains can be produced only if the minerals concerned are mechanically anisotropic, i.e., there must be crystallographic planes and lines of maximum ability to deform by gliding. He speaks of minerals such as garnet, which possess no such planes or directions as being " condemned to continual rotation " (*loc. cit.*, p. 172), as evidenced by the well-known spiral arrangement of inclusions in " snowball " porphyroblasts of garnet.

PLASTIC DEFORMATION OF ROCK COMPONENTS.

As early as 1849 Sharpe suggested that flattening of the component grains at right angles to a compressive force was responsible for the parallel fabric of slates (cf. Harker, 1932, p. 154). Geologists of the Wisconsin School (e.g., Leith and Mead, 1915, pp. 177, 178) also attached some importance to mechanical elongation of rock components parallel to the schistosity (as evidenced by deformed crystals, pebbles and fossils). Examples of undoubted flattening, bending and general distortion of grains have been described and figured in many subsequent works on " dynamic " metamorphism (e.g. Sander, 1930, Fig. 66; Harker, 1932, Fig. 184 B).

During the last dozen years the role of deformation of crystals in metamorphism has been critically examined in the light of a mass of data accruing from petrofabric analysis of naturally deformed rocks and from experimental investigation of the behaviour of rocks in the laboratory under high shearing stress and confining pressures. The literature is too extensive to be reviewed in this account,* but some conclusions regarding mechanism of grain deformation are summarised below; others are discussed in a later section dealing with the relation of schistosity to the directions of deforming forces and movements.

When a rock is being deformed its component grains are subjected to differential stresses the intensity of which varies in different planes and directions within each grain, as determined by the position of the grain in relation to the stress system affecting the rock body. A grain may react to these imposed stresses in one of two ways, according to whether the stress exceeds on the one hand the frictional resistance to intergranular movement along boundaries between adjacent grains, or on the other the elastic limit of the mineral for a particular crystallographic direction. In the former case intergranular rotation is possible. In the latter case the crystal will deform by gliding parallel to that crystallographic plane and direction for which the elastic limit has been exceeded. Most rock-forming minerals possess crystallographic planes and directions of potential gliding [whether by twinning or simple translation (cf. Knopf, 1938, pp. 88, 89)], and when these coincide approximately with the planes of maximum shearing-stress for the deforming rock body, conditions most favourable to grain deformation by gliding are realised. Neglecting the complicating factors discussed by Schmidt and Eskola in the works cited above, it will readily be understood that intergranular rotation, combined with gliding of grains that have attained a favourable orientation, might give rise to a high degree of preferred orientation according to space-lattice structure for the mineral concerned. The resultant schistosity (or schistosities) might be parallel to the planes of slip in which the crystal glide-planes have become oriented throughout the rock, or it might be governed by a parallel dimensional orientation of the elongated grains (not necessarily parallel to the slip-planes of the rock-body) produced as a secondary result of grain deformation (see later, p. 137).

A programme of experimental work on deformation of rocks and crystals at high confining pressures was initiated a few years ago by D. Griggs and important results have already come to hand (Griggs, 1936, 1940; Griggs and Bell, 1938). Marble cylinders, jacketed to exclude water from the intergranular pores, were compressed under confining pressures of 8,000–10,000 atmospheres with resultant shortening of 4–25% (Griggs, 1936, pp. 566-569). Microsections of the deformed rock showed no effects of rupture nor any marked change in size or shape of grain. Lamellar twinning on

* The reader will find numerous references in the accounts by Sander (1930, pp. 147–156) and Knopf (1938, especially pp. 86–99, 163–178) and in Eskola's recent critical summary (Eskola, 1939, pp. 297–308).

$(10\bar{1}2)$ was developed to a very high degree showing that flow was accomplished by twin-gliding. Furthermore, the component grains had reached a high degree of preferred orientation according to space-lattice structure, with the twinning planes inclined at high angles to the direction of the compressing force—a pattern familiar enough in fabric diagrams of rocks that have been deformed by Sander's process of *flattening* (see below).

Nevertheless Griggs (1940) urges exercise of great caution in applying the results of high-pressure experiments to the interpretation of natural rock fabrics. The high confining pressures employed greatly increased the strength of the materials tested; in one case a five-fold increase of strength was reported for a confining pressure equivalent to a depth of 22 miles in the earth's crust. It is thought very unlikely that differential stresses sufficient to overcome this increased strength are in fact developed within the earth's crust. Experiments on single crystals of quartz failed, even at the highest pressures available, to produce plastic flow by translation or twinning (Griggs and Bell, 1938).

Further experiments are being carried out to determine the effects of time, temperature and the presence of solutions in the intergranular pores in deformation by flow. The first results available (Griggs, 1940) indicate that the presence of solutions is of great importance in reducing the strength of marble. Test pieces immersed in carbonated water were found to flow readily at stresses of one-fifth the magnitude recorded for the previous experiments in the absence of water. Deformation was accomplished mainly by recrystallisation, however, and no marked effects of twin-gliding were recorded.

RUPTURE OF GRAINS.

When a rock is deformed beyond the elastic limit under low confining pressures and if recrystallisation is unimportant, catalastic rupture and breaking down of the original grains is the mechanism involved. Neither schistosity nor any type of preferred orientation of grains need result from pure cataclasis, though actually simultaneous rolling out and rotation of the fractured material usually gives rise to a preferred orientation governed by external form of the fragments (cf. Harker, 1932, pp. 168, 169). The reader is also reminded that rupture of individual grains also may accompany plastic deformation of the rock as a whole, for "although the individual elements may be ruptured, the rock itself retains its continuity in space, because indirectly related crystallising movements either work *pari passu* with the ruptural or plastic deformation, or follow the rupture before the continuity is lost" (Knopf, 1938, p. 38).

Bearing in mind this complex interplay between rupture, plastic deformation and crystallisation of the rock components during deformation which may be termed plastic with reference to the rock-mass as a whole, it will be readily understood that fracturing of grains may possibly play an important part in the evolution of preferred orientation of grains according to space-lattice structure,

provided that the form of the fragments produced is related to the space-lattice. Recent petrofabric studies and the results of high-pressure deformation of quartz crystals while not conclusive nevertheless suggest strongly that the preferred orientation of quartz in deformed rocks may well be controlled by fracturing of crystals along planes of weakness in the lattice. The most significant conclusions arrived at with regard to quartz are as follows:—

(1) Sander (1930, pp. 173–178) believes that the predominating process of orientation of quartz in deformed rocks is one by which the grains of quartz break down by fracture into needles elongated parallel to the *c* crystal axis. These needles are then assumed to become oriented by the shearing movements so as to lie in the slip-planes of the rock mass, with their long axes parallel to the direction of movement. It should be noted that this is merely a hypothesis based upon observations within large undulose grains of quartz, and the results of many fabric analyses of quartz in a variety of rock types.

(2) Eskola (1939, pp. 303, 304) following Schmidt's conception of plastic deformation of quartz grains by translation-gliding on the basal plane, unit prism and unit rhombohedron, and taking into account the studies of Hietanen (1938) upon undulose quartz grains in Finnish quartzites, concluded that rupture along surfaces parallel to the vertical crystal axis combined with flexure-gliding in the basal plane is one of the main orienting mechanisms.

(3) Griggs and Bell (1938) found that at extreme confining pressures quartz will not deform plastically but behaves elastically up to the point of rupture. Moreover, the differential stress necessary to cause rupture under high confining pressures was found to be very great indeed. However, in the presence of water and Na_2CO_3, though again there was no plastic deformation, rupture was effected at much lower differential stresses—the magnitude of which is reconcilable with values obtaining in actual deformation in the outer part of the earth's crust. The quartz under these circumstances showed a strong tendency to fracture into needle-like fragments elongated parallel to the *c* axis, the unit rhombohedron or the basal plane. If these fragments now become dimensionally oriented in the manner assumed by Sander, the several possible resultant lattice orientations would correspond well with the principal types of quartz orientation generally recognised by Sander and others in actual fabric diagrams. This same thesis has been elaborated somewhat by Fairbairn (1939).

Paratectonic Crystallisation.

Crystallisation proceeding simultaneously with deformation has long been recognised as a most important factor in connection with the development of schistosity. There has, however, been a good deal of confusion and lack of agreement as to the relative effectiveness of several mechanisms of crystallisation.

(1) *Riecke's Principle:* Schistosity governed by strong preferred dimensional orientation of mineral grains, supposedly in a plane perpendicular to a simple compressive force, has been

attributed by many writers to recrystallisation controlled by "Riecke's principle." Riecke's papers are not available to the present writer, but more than one process of orienting appears to be concerned in "Riecke's principle" as described in current literature.

Johnston and Niggli (1913, pp. 610, 611) summarise the principle thus: ". . . when a crystal is strained, the solubility of the strained face is increased. Consequently material tends to dissolve off the strained faces of a crystal in contact with a saturated solution in any solvent, and to be redeposited where the strain is less. This does not necessarily imply that the mineral be redeposited on the unstrained faces of the original crystals; it may go to form new crystals. In very many cases, of course, a reaction or transformation will occur, so that the mineral will not be redeposited in its original form." The same authors then go on to deduce that both the original and the newly growing grains will tend to be elongated in the plane perpendicular to the direction of greatest stress. The two complementary mechanisms involved are deformation (flattening) of the pre-existing grains and simultaneous growth of new grains in unstressed positions (cf. also Harker, 1932, p. 145; Eskola, 1939, pp. 282, 283). The former could give rise only to a dimensional orientation of grains which would still retain their initial random lattice orientation. But the newly growing crystals could assume a preferred orientation according to space-lattice, provided the mineral in question is anisotropic and has the capacity to grow more rapidly in one crystallographic direction than in others. This aspect has been stated thus by Eskola (*loc. cit.*, p. 283): "In the growth of the crystals a selection takes place: the crystals situated in the correct position grow further in the schistosity-planes, while the crystals situated transversely to this direction remain smaller and shorter, as is frequently found with the 'cross biotites' or 'cross hornblendes' of the crystalline schists. If the mineral possesses a favoured direction of growth (e.g. mica, or amphibole) an orientation thus comes into existence—*crystallisation-schistosity.*"

The effectiveness of Riecke's principle in metamorphism of rocks has been questioned by several writers in the light of petrofabric evidence (e.g. Knopf, 1933, pp. 460, 461, 470; Gilluly, 1934, p. 191; Fairbairn, 1937, pp. 61, 62); nor does Sander (1930) attach any weight to it. On the other hand Niggli (Grubermann and Niggli, 1924, p. 464) and Eskola (1939, pp. 294, 295) believe that the Riecke principle can be effective, *acting in conjunction with other mechanisms,* in cases where the direction of the compressive force is approximately perpendicular to the schistosity. This condition is believed to hold for those steeply dipping schists of fold-mountain regions, the deformation of which Sander describes as "flattening" often without much tectonic transport.

The results of fabric analysis show clearly that Riecke's principle is much less generally applicable as an explanation of crystallisation-schistosity than was once thought to be the case. As far as

the present writer is aware no instance is known of a fully investigated schist fabric that may be attributed wholly and without doubt to its influence. Moreover, if orientation by space-lattice is taken into account in conjunction with the more obvious preferred orientation according to grain-form, it is difficult to visualise how the operation of Riecke's principle could explain any of the following very commonly occurring cases:—

(a) Fabrics in which mineral grains with strong lattice orientation related to the schistosity show no obvious preferred dimensional orientation. The quartz and calcite fabrics of many rocks possessing crystallisation schistosity belong to this category. It seems reasonable to infer that dimensional orientation of platy or prismatic minerals in the same rock is secondary and depends primarily upon lattice orientation of the grains in question.

(b) Fabrics with strongly developed girdle patterns such as are common in B-tectonites. The fabric is symmetrical about a line in the schistosity plane, not the normal to the schistosity as demanded by Riecke's explanation.

(c) Fabrics in which strong dimensional orientation with elongation of grains in the plane of schistosity is accompanied by a lattice orientation that cannot be correlated with the schistosity. For example, in many of the rocks where schistosity has developed by "flattening" the grains of quartz, noticeably elongated in the plane of schistosity, have their optic axes in one or other of two planes that intersect the schistosity-plane obliquely.

(2) *Sander's Views on Paratectonic Crystallisation:* Sander (1930, pp. 115, 269-275) distinguishes between two types of componental movement by which deformation is achieved in metamorphism: direct componental movements including mechanical deformation and rotation or sliding of grains, and indirect componental movements involving transport of atoms or atomic groups by such means as solution and re-deposition, diffusion through pore solutions, convection governed by temperature gradients, and migration of solutions under the influence of pressure gradients, insofar as all these movements are related to the process of deformation. The velocity of movement of individual grains is always extremely slow, but for a deformation of constant velocity is proportional to the size of the grains concerned. Solution and redeposition of minerals such as quartz or calcite is also a slow process and requires a minimum time in which to be effected. If, then, the velocity of mechanical movement of grains exceeds a limiting value, solution and crystallisation of mobile material are impossible. On the other hand, if mechanical deformation is sufficiently slow and the rock sufficiently fine in grain paratectonic crystallisation can occur. Increased temperature, too, will speed up chemical reactions and will therefore favour crystallisation (cf. Turner, 1941, pp. 12–14). Crystallisation is specially active on the boundaries of larger pre-existing grains and along surfaces of discontinuity due to shearing or tensional rupture, and by healing the small-scale fractures considerably assists in preserving the continuity of the rock during deformation (cf. Knopf, 1938, p. 38).

Paratectonic crystallisation as pictured by Sander* usually leads to establishment of some type of preferred orientation of the growing grains. Three possibilities have been recognised from analysis of fabric:—

(a) By recrystallisation without any rotation of grains a lattice-orientation may develop similar to that arising from direct componental movements (plastic deformation, rotation of grains, etc.). An instance of partial recrystallisation of quartz illustrating this principle was examined in great detail by Sander and has been cited by Mrs Knopf (Knopf, 1938, pp. 148, 149, Fig. 40; p. 171) who states that this is one of the most important explanations of the development of preferred orientation in tectonites.

(b) During the early stages of deformation the small "seed-crystals" assume a tectonite orientation (according to space-lattice) by combined operation of the intergranular and intragranular movements described in earlier sections of this paper. When in the later stages of deformation paratectonic crystallisation becomes effective the earlier preferred orientation related to the still effective movement-plan is preserved in the recrystallised rock.

(c) Sander attaches considerable importance to the principle of growth of crystals with their long axes in the direction of the greatest ease of growth (*Wegsamkeit*), thus giving rise to dimensional and lattice orientation of grains (cf. Eskola, 1939, p. 294). Crystallisation of this type may be either paratectonic or post-tectonic. It is therefore discussed more fully below.

(3) *Experimental Results:* The work of Griggs (1938) on the plastic deformation of marble and limestone at high confining pressures has shown that recrystallisation, made possible in his experiments by the presence of Na_2CO_3 in solution, is probably of great importance in natural deformation of rocks in the accessible portion of the earth's crust. While it was impossible to produce plastic deformation of dry quartz even at enormous confining pressures, preliminary results suggest that quartz, too, becomes mobile in the presence of solutions and can deform plastically by recrystallisation.

POST-TECTONIC CRYSTALLISATION.

From fabric studies it seems probable that crystallisation processes commonly continue to operate after active deformation of the rock has ceased and while the temperature of metamorphism still

* In a recent discussion on the origin of "flow cleavage," C. O. Swanson (1941, p. 1249) first defines as "hypotheses of movement" those that attribute preferred orientation purely to mechanical movements (direct componental movements in Sander's terminology). Himself an advocate of the hypothesis of recrystallisation of mineral grains with their cleavages and longest dimensions perpendicular to the direction of maximum stress, Swanson (*loc. cit.*, p. 1252) then states, in criticism of Sander's views, that ". . . the Sander school attributes to movement all the oriented fabrics of deformed rocks." This hardly conveys an adequate picture of the complex interplay of crystallisation and mechanical movement visualised by Sander. According to Swanson rock flowage is brought about by indirect componental movement exclusively; Sander pictures indirect and direct componental movements acting together, not the latter alone as implied in the above quotation.

remains high. Apart from change in size of grain this post-tectonic crystallisation may affect the fabric in any of three ways:—

(a) Where the rock fabric is already anisotropic as a result of strong penetrative movements during the deformational phase of metamorphism, the fabric planes upon which slipping occurred are now surfaces of readiest migration of pore solutions, i.e., surfaces of greatest ease of crystal growth. " Those crystals that have their directions of most rapid growth in the fabric in the schistosity plane become elongated in this direction, as for example the amphibole pencils of *garbenschiefer*. In rocks with a purely plane schistosity, the amphibole prisms lie unoriented in the *s*-planes; in rocks with linear schistosity . . . the *c* axes of the amphibole lie subparallel to the axis of lineation, no matter whether this represents the tectonic axis b = B (as usually in overthrust sheets) or whether it is parallel to the glide direction a (as in most fusion tectonites with fluidal fabric and in shear-surface mylonites)" (Eskola, 1939, p. 294). The resultant grain orientation is essentially dimensional, and the schistosity is a type of *crystallisation-schistosity*. Growth of crystals has not caused the schistosity but has merely preserved and emphasised a set of *s*-planes already in existence (Knopf, 1938, p. 68). It must be borne in mind that the original *s*-planes may in the first place have originated in a number of different ways, e.g., as shear-surfaces, fracture cleavages, etc., and even need not be connected with deformation of any sort. Thus *s*-planes of purely sedimentary origin in a shale may give rise, on recrystallisation and reconstitution of the rock in the absence of differential stress, to a well-defined schistosity; the rock in question though schistose, is not a tectonite. Schistosity parallel to bedding is probably more often due, however, to development of slip-surfaces parallel to bedding in the manner described in an earlier section (cf. Eskola, 1939, p. 295).

(b) Post-tectonic mimetic crystallisation may also preserve an earlier preferred orientation according to space-lattice, that has developed during a pre-crystalline or paracrystalline deformational phase of metamorphism. This process may be compared with annealing of cold-worked metals, and seems from results of fabric analysis to play a notable part in the development of coarse-grained schists with lattice-orientation.

(c) Under other circumstances, recrystallisation of a particular mineral after deformation has ceased may destroy the original lattice orientation. This mechanism has been suggested by Sahama (1935, p. 20) and Eskola (1939, p. 295) as a possible explanation for the almost unoriented condition of the quartz in certain granulites from Greenland and Finland. While noting that cases of " unorienting " must be common in rocks that recrystallise or are chemically reconstituted at high temperatures, Eskola (*loc. cit.*) states that anisotrophy, once attained by orienting of grains in a rock mass, persists for a very long time and exerts a powerful control over its response to differential stresses in later deformations.

KINDS OF SCHISTOSITY IN RELATION TO MOVEMENTS AND FORCES OF DEFORMATION.

From the above discussion it is clear that schistosity is seldom a product of any one simple process, but rather of several processes operating simultaneously or in sequence, in accordance with a definite symmetrical *movement-plan*, which in turn is controlled by a system of forces acting upon the rock mass. Whereas it is usually possible by combining field and laboratory observations upon rock fabrics (including the elaborate investigations involved in petrofabric analysis), to synthesise the movement-plan in some detail, and even to trace changes in its pattern when such occur, it is always more difficult and often impossible to reconstruct an accurate picture of the force system that governed the movement. Until Sander's work became known, most writers on schistosity attempted to correlate it with some simple system of deforming forces, and many made use of the strain ellipsoid in this connection. It was common practice, too, to generalise too widely from particular cases and to admit only one general type of correlation between schistosity and deforming forces as being possible. Prevalent views, some of which are still found in current text-books, include the following:—

(1) Schistosity always perpendicular to a compressive force (e.g., Sharpe, Sorby, Harker), (cf. Harker, 1932, pp. 154, 155, 193–195; Swanson, 1941, pp. 1249, 1250, 1259).

(2) Schistosity involving preferred dimensional orientation of crystals, always parallel to the AB plane of the strain ellipsoid, i.e., perpendicular to the direction of maximum shortening of the mass. For a simple compression as between the jaws of a vice, the schistosity would be at right angles to the compressing force (Leith and Mead and followers of the Wisconsin School) (cf. Leith and Mead, 1915, pp. 169-182; Turner, 1936, pp. 203, 204; Mead, 1940, p. 1010). Fracture cleavage was interpreted as a shear-phenomenon of independent (later) origin.

(3) Schistosity parallel to shear surfaces (Becker) (cf. Becker, 1907; Turner, 1936, pp. 204, 205). Two possibilities were recognised:

(a) Two equal intersecting schistosities with the direction of the compressive force bisecting the obtuse angle of intersection.

(b) A single well-defined schistosity (the usual case) crossed by simultaneously developed fracture cleavage; the major axis of the strain ellipsoid bisects the acute angle of intersection (Becker, 1907, Fig. 6, p. 13; Sander, 1930, Fig. 44, p. 101); the deforming force, exact direction unknown, is oblique to the schistosity.

The work of Sander, Schmidt and their co-workers in petrofabric analysis can be applied to the problem of schistosity in relation to deformation if it be assumed that the features of a tectonite fabric conform to the symmetry of the movement-plan under whose influence the fabric developed. That such is essentially the case cannot be doubted by anyone familiar with the quantity of petrofabric data now available. These modern investigators of fabric recognise that none of the above three theories of schistosity is either

wholly wrong or universally applicable; but it seems likely that Becker's long-neglected theory of schistosity as a shear phenomenon, when modified to some extent, furnishes the most generally applicable explanation of schistosity. Workers on petrofabrics correlate *s*-surfaces of all kinds with deforming *movements,* but do not attempt anything more than a very broad correlation with deforming *forces.* They have shown that several sets of schistosity-surfaces may originate in a single deformation (as Becker insisted), though it is also possible for a second schistosity to be superposed upon *s*-planes of an earlier deformation. Interpretation of schistosity, therefore, requires great care and should be based upon as full data as possible. The following possibilities are recognised:—

(1) In most schistose rocks that have been deformed by penetrative movement affecting the component grains the *tectonic axis* of the deformation is parallel to the trend of the *lineation* (*b* fabric axis) in the principal plane of schistosity. The tectonic axis is also parallel to the axis of folds developed at the same time as metamorphism and is therefore the most important recognisable direction in the fabric—more useful in working out the tectonics of the area than is the schistosity itself. It is perpendicular to the direction of slip movement in shear-planes and parallel to the axis of rotational movements connected with deformation. Lineation in a schist may be due to one or more of four structural characters: (a) intersection of two contemporaneously developed sets of slip-surfaces parallel to (*h0l*) of the fabric;* (b) microfolding of alternating micaceous and quartzo-feldspathic layers; (c) growth of pencils of minerals such as quartz and feldspar in a micaceous or chlorite matrix; (d) elongation of mineral grains parallel to the lineation. Sander (e.g. 1934, pp. 42, 43) has distinguished two cases corresponding to two distinct types of deformation; in one the tectonic axis is nearly horizontal; in the other it is approximately vertical. In either case fabric analysis typically yields orientation diagrams with well developed girdles the axis of which is the lineation *b*. A special case where the macroscopic lineation is not parallel to the tectonic axis is described below under (3). For a good example of the use of regional mapping of linear structure in a tectonic study, see Phillips, 1937, pp. 591–597.

(2) The most widely occurring type of schistosity is that which develops parallel to surfaces of slip that commonly though by no means always coincide with pre-existing *s*-planes (especially bedding planes). Possible distinctive criteria are: lineation parallel to the tectonic axis *b*; presence of several sets of visible schistosity surfaces (sometimes including surfaces of strain-slip or fracture cleavage) intersecting in *b*; rotational structures visible in thin sections and polished sections cut at right angles to *b*; pencil structure parallel to *b*; tension joints perpendicular to *b*; girdle patterns in fabric diagrams. When fabrics of this type characterise large areas of rocks in which the schistosity is sub-horizontal except for the effects of post-metamorphic dislocations, the schistosity is probably due to slip

* Lineation due to intersection of two sects of *s*-surfaces belonging to two different deformations has no such significance and is not a tectonic axis.

accompanying regional alpine thrusting movements, e.g., the Shuswap terraine of British Columbia (Gilluly, 1934); the Central Otago schists of southern New Zealand (Turner, 1940). This is especially likely if the trend of the lineation is fairly constant over wide areas. In the past such areas have been cited as instances of static recrystallisation under vertically directed load, but this explanation cannot be reconciled with the movement-plan deduced from the fabric (see especially Gilluly, 1934).

(3) In local zones of mylonitisation and on slickenside surfaces the fabric is the result of more intense though localised deformation and much more rapid translatory movement than accompanied deformation of the schists described in the preceding paragraph. The linear structure is parallel, not perpendicular, to the direction of movement, and is not the tectonic axis of the deformation. Corresponding fabric diagrams usually fail to show a girdle pattern or if a girdle is present its axis is perpendicular to the linear structure. Similar lineations parallel to the direction of flow are, of course, well known in gneissic igneous rocks the fabric of which has been determined by movement in a partially molten mass.

(4) A type of schistosity prevalent especially in rocks metamorphosed in deep-seated zones now exposed in certain Precambrian terraines, is one which usually dips steeply and appears to have developed at right angles to a simple compressive force. Many of the rocks of the Lake Superior region described by Leith, Mead and others as having " axial-plane foliation," and the Finnish granulites studied by Eskola, Sahama, Hietanen and co-workers belong to this category. Sander applied the term " flattening " (*Plättung**) to this kind of deformation, for details of which the reader is referred to Sander (1930, pp. 219, 220), Knopf (1938, pp. 69, 145–149), and especially Eskola (1939, pp. 286, 300–302). The essential mechanism of deformation, as described by Eskola, is as follows:—In a rock mass slip commences on two planes of maximum shearing stress originally inclined at 45° to the compressing force. As slipping movement continues these planes rotate in opposite directions about their line of intersection (*b* fabric axis) and at last approach mutual parallelism when they come to be at high angles to the compressive force. Any crystal that becomes oriented in either major slip-plane, whether dimensionally or so as to allow translation of the individual grain on a crystallographic plane of potential gliding or twinning, is by this means slowly rotated about *b* until at last both the direction of elongation of the grain and its plane of translation (if present) approach perpendicularity to the direction of compression. In this way a surface of schistosity (*ab* of the fabric) comes into existence, which is determined mainly by the flattened outlines of the grains; if the two original major slip-planes (now nearly parallel) remain distinctly differentiated, the megascopic schistosity is a compromise between the two. The schistosity may be emphasised by post-tectonic mimetic crystallisation, and Eskola (*loc. cit.*) believes that Reicke's principle may be a contributing factor in development of the characteristic elongated form of the grains. Now although any

* Translated as "plaiting" by some authors.

major slip-plane in the rock mass, once developed, commences to rotate towards the *ab* position, the maximum shearing-stress still continues to operate in planes, fixed in space, at 45° to the direction of compression. In the case of quartz and calcite, which adapt their space-lattice orientation to a new stress system much more readily than micas or hornblende, many of the grains that have been greatly flattened in *ab* as described above have adjusted their internal structure to the stress system still operating in the closing stages of deformation, i.e., with their crystallographic translation-plane parallel to one of the planes of maximum shearing stress. For such minerals there is no relation between space-lattice and dimensional orientation in rocks deformed by flattening. Characteristic features in the fabric of flattened rocks are:—Strong dimensional orientation of mineral grains with pronounced flattening parallel to the schistosity and elongation parallel to the lineation (this applies to quartz and calcite as well as to minerals with flaky or prismatic habit); micas and chlorites lie with the basal plane subparallel to the schistosity and corresponding fabric diagrams show a single maximum somewhat drawn out transversely to the lineation (submaxima are absent, and girdles are incomplete); quartz and calcite diagrams show maxima symmetrically developed on either side of the schistosity plane, or else a series of submaxima symmetrically developed about the pole of the schistosity and representing positions of concealed slip-planes in various stages of rotation about *b*; tension joints parallel to *ac* (i.e. perpendicular to the lineation) are usually well developed and may be closely spaced in the quartzose layers as seen microscopically.

(5) When compression has produced only a relatively slight displacement of the flattening type and subsequent or simultaneous crystallisation of mica, etc., preserves and emphasises the two sets of fabric planes on which slipping took place, the result is a pair of microscopically distinct equally developed schistosity surfaces, the obtuse angle of which is bisected by the compressing force. Rotational structures are absent and the lineation is due purely to the intersection of the two sets of schistosity surfaces. Corresponding fabric diagrams show an orthorhombic symmetry and the two sets of schistosity should be represented clearly by maxima for both micaceous minerals and quartz or calcite. There is complete graduation from fabrics of this type, through fabrics in which the visible slip-planes intersect at progressively more acute angles, to typical flattened fabrics such as those discussed above under (4).

(6) Schistosity may also be a product of simple recrystallisation unconnected with deformation but preserving an earlier set of surfaces of non-tectonic origin (e.g., bedding). Distinguishing criteria of such fabrics are: absence of lineation; absence of (*h0l*) surfaces, *ac* joints, etc.; development of dimensional and corresponding space-lattice orientation of minerals with pronounced crystallographic habit such as micas or hornblende; for minerals like garnet, quartz or calcite, which do not develop a pronounced crystallographic habit under conditions of metamorphic growth, there may or may not be a dimensional orientation, but space-lattice orientation is never developed.

(7) Rarely, tension fractures parallel to the *ac* fabric plane are so closely spaced as to give rise to a parallel parting that can be termed schistosity (Sander, 1930, p. 219; Eskola, 1930, p. 309). Schistosity of this type should be easily distinguishable by its relation to other schistosity surfaces and epecially by its orientation at right angles to the lineation, i.e., to the axis of the mica girdle (if present).

(8). The presence of two intersecting sets of schistosity surfaces (one of which may often be a strain-slip cleavage) may be due to the superposition ("overprinting") of one deformation upon another, or to a change in the movement-plan in the later stages of a long-continued deformation (cf. Ingerson, 1936; Knopf, 1938, p. 149; Turner, 1940, p. 189). The presence of two intersecting lineations (one of which is a tectonic axis) in the principal schistosity is a certain magascopic indication of this condition. In corresponding fabric diagrams the axes of the mica and quartz girdles usually fail to coincide, since in most cases the quartz fabric alone bears the imprint of the last deformation. Sometimes it is also possible from the texture alone to determine that crystallisation has been post-tectonic (with reference to the last deformation) for some constituents, pre-tectonic for others.

(9) In folds originating through flexural-slip, the slip-surfaces and the corresponding schistosity of the type described under (2) above lie parallel to the bedding. On the other hand, in pure slip-folds schistosity originating by slip trends parallel to the axial planes of the folds. Also parallel to the axial planes is schistosity developed by flattening [cf. (4) above] when this is present in folded rocks.

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The Ellipticities of Surfaces of Equal Density in the Earth's Interior.

By K. E. BULLEN, University of Melbourne.

[*Read before the Wellington Branch, July 9, 1942; received by the Editor, April 7, 1942; issued separately, September, 1942.*]

1. FIGURES for the ellipticities of surfaces of equal density within the Earth's interior were previously published by the writer (1936), being based on the solution there given of the problem of the Earth's density variation. Since this date, there have been several improvements made, notably by Jeffreys and by Gutenberg and Richter, to the travel-time tables of seismic waves; and the writer has in consequence found it necessary to make certain modifications to the density values. These would, of course, entail alterations to the previously given ellipticity figures, and Lambert (1939) drew attention to the fact that revised ellipticity figures had not been published in detail by the writer. But, as pointed out by the writer (1937), any alterations which might then be made to the ellipticity figures would be small, and in view of this it was felt best to defer a detailed revision until such time as the seismological data and corresponding density figures had reached a greater degree of finality.

This stage appears now to be reached—see Bullen (1941)—and two recent papers (1940, 1942) contain a fairly complete account of the extent of residual errors likely to be present in the writer's most recent density figures. The degree of precision obtained from this analysis suggests that it is now worth while re-discussing the question of the ellipticity figures.

2. In carrying out the calculations, use was again made of the parameter η, where

$$\eta = \frac{d \log \epsilon}{d \log r} , \tag{1}$$

r being the distance of a point from the Earth's centre, and ϵ the ellipticity of the surface of equal density through this point. Let m be the mass of the matter enclosed by this surface, and I its moment of inertia, and let

$$I = zmr^2 . \tag{2}$$

Values of the coefficient z are readily obtainable from the figures for the Earth's density distribution, and η is then found from the equation

$$\eta = \left\{\frac{5}{2}\left(1 - \frac{3z}{2}\right)\right\}^2 - 1 . \tag{3}$$

Equation (3) is an approximate equation given by Darwin in his theory of the figure of the Earth, and the validity of the approximation depends on the range of variation within the Earth of a certain function of η. The question of this range of variation, in so far as it is relevant to the present problem, has been considered in the writer's earlier paper (1936) and the validity of the use of equation (3) substantiated. (The writer hopes shortly to publish an alternative and more direct discussion on this point). With values of η then determined from (3), the desired values of ϵ are finally found using (1).

In the following table, values of ϵ as thus computed are given in terms of the depth d km. below the Earth's surface. Corresponding values of the coefficient z and the parameter η are also included, the latter being sometimes directly useful in other calculations relating to the Earth's interior—see Bullen (1938).

d	z	η	ϵ
0	0.334	0.56	0.00337
200	0.337	0.53	0.00331
400	0.340	0.50	0.00325
600	0.342	0.49	0.00320
800	0.342	0.48	0.00315
1000	0.342	0.48	0.00309
1200	0.341	0.49	0.00303
1400	0.341	0.49	0.00298
1600	0.342	0.49	0.00292
1800	0.343	0.48	0.00286
2000	0.344	0.46	0.00280
2200	0.347	0.43	0.00274
2400	0.353	0.38	0.00269
2600	0.361	0.32	0.00264
2800	0.372	0.22	0.00260
2900	0.380	0.17	0.00260
3000	0.380	0.16	0.00257
3500	0.378	0.17	0.00250
4000	0.373	0.21	0.00242
4500	0.368	0.26	0.00229
5000	0.382	(0.15)	0.00213
5500	0.399	0.00	0.00212
6000	0.400	0.00	0.00212

It will be found that within the Earth's outer mantle (i.e., down to a depth of 2900 km.) the values of ϵ show little difference from the previous results (1936), the maximum change at any depth being 0·00002. Lambert (1939) gave tentative revised ellipticity values, expressing his results as reciprocals of the ellipticity. Within the Earth's mantle these values need corrections up to 6 units in order to fit the figures given in the present paper.

Within the central core, the present results indicate a variation in ϵ from 0·00260 at the core boundary to 0·00212 at the Earth's centre. The 1936 results, and also the figures of Lambert, showed only very slight variation of ϵ within the central core. The difference between the latter results and the new figures here given is largely due to the effect on the density solution of the new Lehmann-Gutenberg-Richter discontinuity within the central core.

3. It is possible to give some indication of the greatest residual errors to be expected in the values of ϵ appearing in the above table. At all depths within the Earth's outer mantle, the greatest error in ϵ is not likely to exceed 0·00002, so that the figures given for this region of the Earth may be taken as highly accurate. There is greater uncertainty within the central core, as the values of the coefficient z are very sensitive to changes in the value taken for the (unknown) density increase across the Lehmann-Gutenberg-Richter discontinuity. The results in the table were computed on the basis of a density increase of 5·0 gm./cm.^{3} across this discontinuity. An increase of

b gm./cm.^{3}, where $-5<b<5$, in this value of the density jump would have little effect on the value of ϵ at the boundary of the central core, but there would be decreases below this level reaching to approximately 0·00009 b at the Earth's centre.

4. It is of some importance to seismology to investigate the effect of the revision here made on calculations of the ellipticity corrections to the travel-times of earthquake waves. Within the Earth's mantle, the changes from the 1936 results are so small that the effect on the calculations of ellipticity corrections (1937A, 1938A, 1939) for waves that have not penetrated the central core is quite negligible. In the case of the phase PKP (1938) the effect of the changes in ϵ will be insignificant for rays that have not penetrated deeply into the central core. The effect will be greatest with PKP for a ray that has passed through the Earth's centre, but it is easy to show that even here the effect will be always rather less than 0·1 second. This is unimportant, being within the limits of accuracy of the ellipticity tables that have been constructed. Similar consideration holds for other phases that have penetrated the Earth's central core. It is therefore unnecessary to modify at all any of the previously published ellipticity corrections to the travel-time of earthquake waves.

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The Origin of the Lower Devonian Fauna of Reefton, New Zealand; with Notes on Devonian Brachiopoda.

By R. S. Allan.

[*Read before the Canterbury Branch, May 11, 1942; received by the Editor, May 15, 1942; issued separately, September, 1942.*]

In discussing this problem in 1935, the writer (Allan, 1935, pp. 34–6) explained the remarkable resemblance between the characteristic fossils of the Reefton argillites and those of the Upper Siegenian-Lower Emsian of the standard Western European development of the Rhenish facies, by advancing hypotheses which now appear to be untenable.

The main hypothesis was that units of a cosmopolitan Lower Devonian fauna isolated geographically, i.e., not connected by shore-lines, would, if subjected to, or stimulated by, a similar set of environmental controls, contain closely related characteristic fossils.

The reasons for this conclusion were (1) the apparent lack of evidence of faunas of the same facies along possible routes of migration between Europe and New Zealand; and (2) the belief that certain Lower Devonian species-groups of brachiopods, notably the gens of *Spirifer hercyniae* Giebel, and the Leptostrophias, were of world-wide occurrence.

In order to explain the cosmopolitan distribution of brachiopods without recourse to migration along shore-lines it was necessary to put forward the subsidiary hypothesis that these Lower Devonian forms must have possessed much greater powers of larval distribution than do Recent members of this phylum.

Recent work by Shirley (1938) and Caster (1939) suggests that the reasons which appeared to necessitate the main hypothesis are no longer valid. It must, therefore, be rejected, and with it will go the subsidiary hypothesis which was weak from birth.

Shirley (1938, pp. 491–496) has shown that the Bohemian Koněprusy facies, represented in New Zealand by the Baton River Beds, occurs at intervals between north-western France and New Zealand. He suggested that the coastlines of the period run more or less in the same general direction, and that " The general distribution . . . suggests the existence of a Lower Devonian ' Tethys,' the shores of which provided the means by which the shallow-water faunas could spread over long distances " (1938, p. 494).

He also quoted evidence to suggest that the fauna of the more littoral Rhenish facies to which the Reefton fauna belongs, had migrated along a parallel route; recording Rhenish elements from Moravia and the Altvatergebirge in south-eastern Europe; from the Altai and Koktschetau; and from Kwangsi, southern China. Shirley wrote: " The evidence which Allan needed is, therefore, to some extent, supplied by these records. Future exploration will doubltless add to them " (1938, p. 495).

The case for the Bohemian facies is much stronger than that for the Rhenish type. For the latter the picture is not entirely convincing. All the records cited by Shirley refer to areas which presumably formed parts of the northern littoral of Tethys, and the nearest is

still a very long way from New Zealand. Nevertheless, if the acceptance of the hypothesis of a Lower Devonian Tethys in explanation of the distribution of the Bohemian facies is justified on the available evidence, it must also be accepted for the Rhenish facies.

Shirley (1938, pp. 495–6) suggested tentatively that the presence of North American species in the Lower Devonian of New Zealand might be explained by migration along a circum-Pacific route such as was operative in the Triassic period. In this connection Caster's hint (1939, pp. 183–4) of a relationship between New Zealand and northern South America in the Devonian should engender caution.

There is also to be noted Du Toit's hypothesis (1937) of a southern geosyncline, the Samfrau, by which interchange between New Zealand and the "austral" Devonian area of South Africa and South America was possible. This sea-way might presumably have joined the New Zealand section of a circum-Pacific and Tethyan route. The writer, however, deliberately refrained from stressing—in fact minimised the importance of—the insignificant "austral" element in the Reefton fauna, and is of the opinion that Du Toit's hypothesis, whatever its merits on other grounds, is not strengthened by the data presented in the Reefton Bulletin.

In regard to the second reason for the writer's hypothesis of 1935, viz. that certain species-groups of brachiopods had a cosmopolitan distribution in Lower Devonian times, the work of Caster (1939) on the Colombian faunas show that it is probably erroneous.

In just those species-groups on which the writer placed most reliance Caster demonstrated a marked development of homoeomorphy. For example, the writer referred to the genus *Acrospirifer* certain South African-South American species which, on closer study, Caster placed in a new genus *Australospirifer*. In discussing *Acrospirifer* which occurs in the Columbian fauna he stated: "It is truly amazing . . . that none of the superficially similar forms hitherto described from South America and South Africa can be satisfactorily assigned to the same generic group" (1939, p. 155); and continued the "'austral' forms may well be assigned to distinct, albeit homeomorphic genera." (1939, p. 156.)

The writer referred *Leptostrophia concinna* (Morris and Sharpe) of the "austral" Lower Devonian to the species-group of *L. magnifica* (Hall) and the European *L. explanata* (Sowerby). Caster (1939, p. 85) suggested that the "austral" species is to be grouped with *Protoleptostrophia* and is not closely related to *L. magnifica* of North America.

It is thus clear that new records of Lower Devonian faunas of both the Rhenish and the Bohemian facies, together with the demonstration of widespread homoeomorphy among Lower Devonian brachiopods leading to the recognition of generic groupings at variance with those suggested by the writer, undermine the earlier reasoning, and force the rejection of an untenable hypothesis.

In its place the writer is constrained to accept the view that the origin of the Lower Devonian fauna of the Reefton Beds is to be explained by migration along shore-lines by a route or routes still imperfectly known but of which the most probable and important was the Tethys sea-way.

NOTES ON DEVONIAN BRACHIOPODA.

Genus CYMOSTROPHIA K. E. Caster, 1939.

Bull. Amer. Paleont., No. 83 (April 8), pp. 39–40.

Type (by original designation): *Leptaena stephani* Barrande, 1848.

Cymostrophia stephani (Barrande).

1938. *Stropheodonta stephani* (Barr.), Shirley, *Quart. Journ. Geol. Soc.*, Lond., xciv (4), pp. 469–470, pl. XLI, figs. 11–12.

Remarks: Caster, in a brief comment on Shirley's monograph, stated: "Shirley's *Stropheodonta stephani* (Barrande) is indubitably closely allied to Barrande's species, and is therefore certainly assignable to the new genus *Cymostrophia* of which Barrande's species is the genotype." (1939, p. 183.)

According to Caster, this genus, which belongs to the Douvillinoid Stropheodontids (family Stropheodontidae) is typically boreal, occurring in the Helderbergian, Oriskanian and Ulsterian series of North America, and in the Koneprusy F2 fauna of Bohemia. Caster described three new species from the Devonian of Colombia (the Floresta Fauna), but the genus is not known from the "austral" faunas of the remainder of South America or from South Africa.

C. stephani (Barrande) is one of the most abundant species of the Baton River Beds.

Genus RHYTISTROPHIA K. E. Caster, 1939.

Bull. Amer. Paleont., No. 83 (April 8), pp. 86–7.

Type (by original designation): *Stropheodonta beckii* Hall.

Rhytistrophia shirleyi n.sp.

1938. *Leptostrophia explanata* Shirley, *Quart. Journ. Geol. Soc.* (Lond.), xciv (4), p. 468, pl. XLI, figs. 7–9 (not of J. de C. Sowerby, 1842).

Holotype, in the Auckland University collection, the original of Shirley's plate XLI, fig. 8, the internal cast of a ventral valve (M654).

Remarks: Caster proposed this genus for a group of corrugated Leptostrophids which occur in the North American Devonian (Helderbergian to Erian), and in the Venezuelan-Colombian Devonian areas of South America. The same author pointed out that Shirley's "*Leptostrophia explanata* (Sowerby) will bear comparison with *Rhytistrophia caribbeana* (Weisbord) from the Cachira series of Venezuela and the variety *colombia* [Caster] from the Colombian Floresta series." (1939, p. 183.)

A comparison of Shirley's pl. XLI, figs. 7–9, with pl. 5, figs. 5, 6, and 13 of Caster's monograph seems to me to justify this conclusion. *Leptostrophia explanata* (Sowerby) belongs to a distinct generic group as Caster (1939, p. 97) has pointed out. I am unable to add to the description given by Shirley, and, until well preserved dorsal interiors are collected, Shirley's description will serve as a diagnosis of the new species.

It may be noted that *Leptostrophia reeftonensis* Allan which I compared with *L. magnifica* Hall and *L. explanata* (Sowerby) is in need of a new generic location (cf. Caster, 1939, pp. 85–86). This question may be left in abeyance until the publication of Caster's promised monograph on the crenulate-hinged Strophomenacea.

Genus HYSTEROLITES Schlotheim, 1820.

1820. *Hysterolites* Schlotheim, *Die Petref.*, pp. 247–250.
Type: *H. hystericus* Schlotheim, 1820.

Hysterolites cf. **hystericus** Schlotheim, 1820.

1935. *Acrospirifer* cf. *hystericus* (Schlotheim), Allan, *N.Z. Geol. Surv. Pal. Bull.*, No. 14, p. 19, pl. II, figs. 4–5.

Remarks: The genus *Acrospirifer* Helmbrecht and Wedekind, 1923, was employed by Allan (1935, pp. 18–19) for a group of Lower Devonian species in which *A. hystericus* (Schlotheim), from the Lower Siegenian, was believed to be the earliest Devonian stage of an evolutionary sequence leading through *primaevus* (Steininger) to *hercyniae* (Giebel) and *paradoxus* (Schlotheim). Unfortunately, Allan failed to investigate the generic name *Hysterolites* Schlotheim, 1820, of which, according to Schuchert and Le Vene (1929, p. 69), the genolectotype is *H. hystericus* Schlotheim. If the generic name is to be used for the complete gens of *Spirifer hercyniae* Giebel (Allan, 1935, pp. 15–17), then *Hysterolites* Schlotheim should be substituted for *Acrospirifer* Helmbrecht and Wedekind.

If, on the other hand, the sequence of species which the writer, following Scupin (1900, p. 132) regarded as a single lineage is not really such, it may be possible to retain both generic terms. This, apparently, is the position adopted by Shirley (1938, pp. 480–1), who used *Hysterolithes* for *Spirifer subspeciosus* (de Verneuil) and *Acrospirifer* for *Spirifer arduennensis* (Schnur). The same usage was employed by Maillieux in 1933*[1]

* (1) *Terrains, Roches et Fossiles de la Belgique*, ed. 2, 1933, pp. 47 *et seq.*

Genus SCHIZOPHORIA W. King, 1850.

1850. *Schizophoria* King, *Mon. Permian Foss. (Pal. Soc.)*, pp. 105–6.
Type (by original designation): *Anomites resupinatus* Martin, 1809, *Petref. Derb.*, t. 49, figs. 13–14.

Schizophoria cf. **provulvaria** (Maurer, 1893).

1935. *Proschizophoria* cf. *provulvaria* (Maurer), Allan, *N.Z. Geol. Surv. Pal. Bull.*, No. 14, pp. 11–12, pl. III, figs. 4 and 7.

Remarks: In their revision of the Orthoidea, Schuchert and Cooper (1932, p. 143) placed Maurer's species in the genus *Schizophoria*; so also did Shirley (1938, p. 465). Schuchert and Cooper referred *Proschizophoria* to the Dalmanellidae; *Schizophoria* to the Schizophoriidae.

There is no justification for the position adopted by the writer.

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A Detail of the Pukaki Moraine.

By R. Speight.

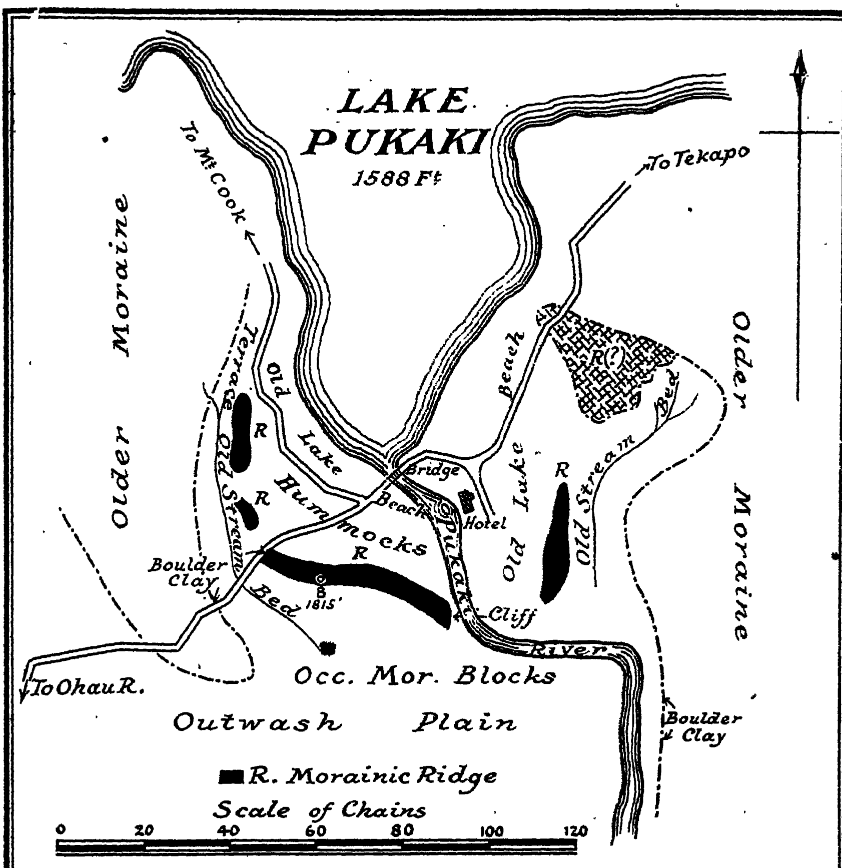
[*Read before the Canterbury Branch, July 2, 1941; received by the Editor, March 9, 1942; issued separately, September, 1942.*]

A. Introductory. (See Sketch Map and Plate 7.)

At the height of the Pleistocene Glaciation of New Zealand, the Tasman Glacier extended from the main divide of the Southern Alps north-east of Mount Cook to about four miles beyond the southern shore of Lake Pukaki, a total distance of about sixty miles. Its end moraine, with adjacent laterals and outwash deposits bounded by moraine, covers an area of over twenty square miles and once formed a barrier extending right across the mouth of the Tasman Valley, but fairly early in its glacial history it was breached near the western end, and the gap so formed acted as the main outflow channel for the glacial and other waters of the Tasman watershed. The water flowing through this gap was in all probability not responsible to any marked degree for the building up of the main outwash plain which forms the floor of the upper part of the Mackenzie intermont. The surface deposits of this are to be credited chiefly to streams which issued from various and fluctuating points of the moraine east of the gap, their former presence being evidenced by numerous abandoned water-courses, some of large size, which originate within or on the outskirts of the moraine, intersect the upper fringe of the plain fronting it, and gradually merge into its general surface.

After a recession of the ice, during which the gap was fully maintained if not actually widened, a re-advancing tongue occupied its floor. Subsequently this was deeply incised by the Pukaki River, and the sections furnished by the latter's steep banks give some insight into the succession of pre-glacial, glacial, and other deposits characteristic of the area.

East of the river, the southern shores of the existing Lake Pukaki rise gently at first, and then more steeply, for some 450 feet, and the land-surface then falls with progressively lower broken cross-ridges having moderate and irregular southern inclination and passing



Sketch Map
OUTLET, LAKE PUKAKI

into more gentle slopes which merge ultimately into the outwash plain. A considerable amount of destruction has been caused by the former outflowing streams, and remnants of old morainic dumps fringe the upper part of the plain, getting less and less definite in form till they disappear entirely, or are represented by sporadic masses, and these in turn become rare and finally are quite absent when the surface of the plain is maturely developed. However, about four miles from the shore of the lake, a series of disconnected, well-developed dumps composed generally of large blocks rises well above the surface. Its line has in general an east-west orientation and just crosses the river to the western bank near the old ford. I know of no definite evidence of the former presence of ice further downstream from this line of dumps. After their deposition the ice must have retreated, become stabilised on the line of the great moraine for a considerable period and developed the outwash plain between it and the dumps just referred to.

On the western side of the river lies a smaller area covered by the main moraine; it is not so high as that on the east, is more hummocky, and was evidently formed of material dumped on ground removed from the direct action of the main ice-stream. It is really latero-terminal moraine.

The surface of the morainic complex facing the lake is covered in general with angular blocks, from the highest point right down to lake level, and it might be a reasonable inference that the whole deposit was composed of similar material, did not the sections alongside the Pukaki River disclose facts discrediting such a conclusion. It should be noted that the present lake lies *behind* the great moraine, but is *not ponded by it*. It may have ponded back an older lake, but there is no definite evidence of its existence.

It will be appropriate at this stage to record the heights above sea-level of various features under consideration as given by the records of the Lands and Survey Department.

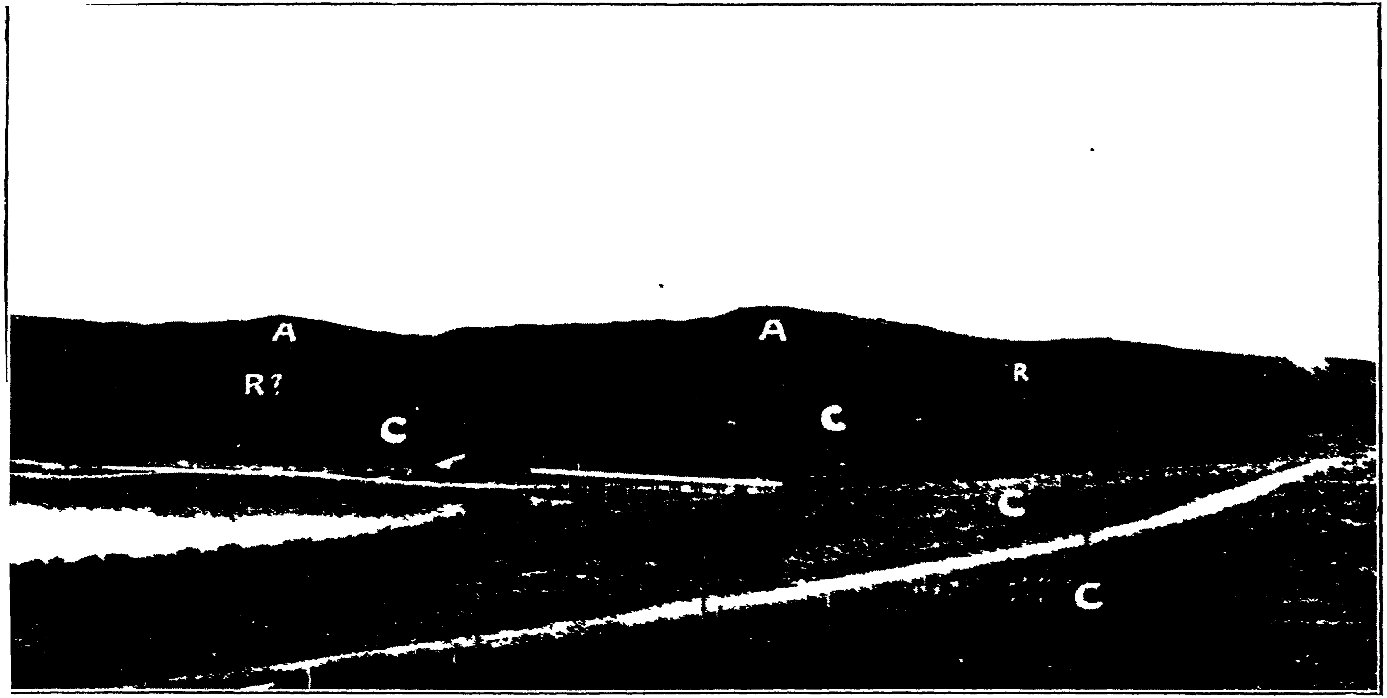
Height of summit of moraine east of the river	2029 feet
Height of summit of ridge west of the river	1914 feet
Height of outlying dumps of main moraine east of the river	1655 feet
Height of upper surface of the outwash plain	1589 feet
Height of plain at maximum extension of the ice	1492 feet
Height of surface of the lake	1588 feet

It should be noted with respect to the last that the level of the lake varies considerably with the season, so the figure must be taken as an approximation. Other heights, as well as the thickness of the beds cited in this account, have been determined as accurately as possible by means of an abney level.

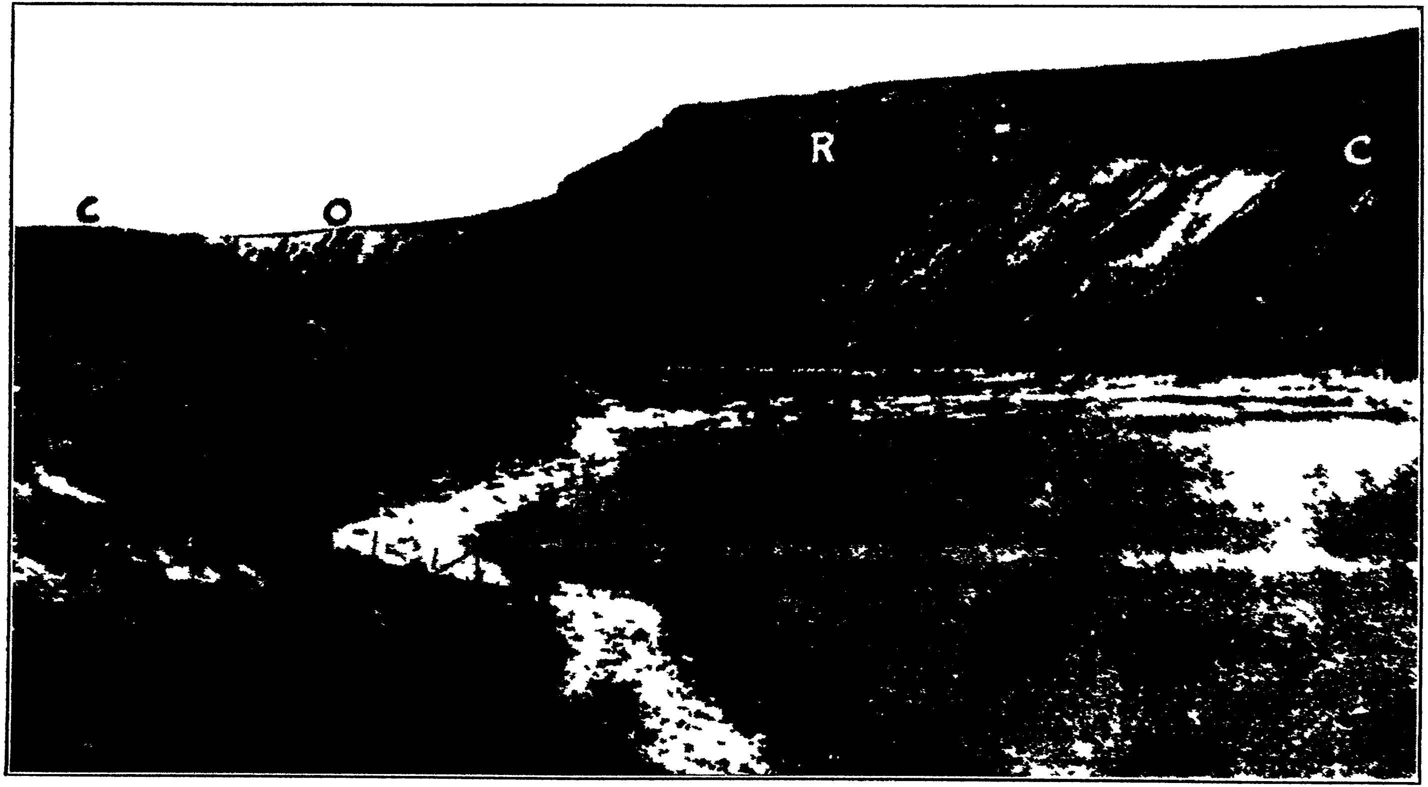
B. Outlet of the Lake. (Plates 7, 8, 9, and 11.)

The river discharges from the present lake through a somewhat open valley cut in gravels and overlying glacial deposits (Plate 7). As the exposures of the beds involved are more clear and complete on the western bank, these will be described first. The surface rises gently from lake level for some seventy feet to an old beach, which is a very persistent feature of the lake shores. There is a narrow bench some ten feet higher, and this is succeeded after another sixty to seventy feet by a shelf formed of irregular mounds, presumably morainic, and then finally by a well-defined, narrow ridge, looking like a terminal moraine (Plates 9 and 11), and ending in a cliff at the river end. It has a fairly even summit, which at Trig. B reaches a height of 226 feet above the lake. Near the cliff-face the ridge bears W.N.W., in its middle section W. 15° N., further west the direction reverts to W.N.W., and this continues as far as the road crossing, beyond which the ridge appears as a detached section with N.W. orientation; and then, after an interval, it is resumed with northerly direction, to terminate about half a mile north-west of the outlet of the lake. At this end lies the deserted bed of an old outflow from the lateral glacier margin (Plate 11), which follows concentrically round the outside of the ridge, channels the outwash plain at first, and finally merges with it.

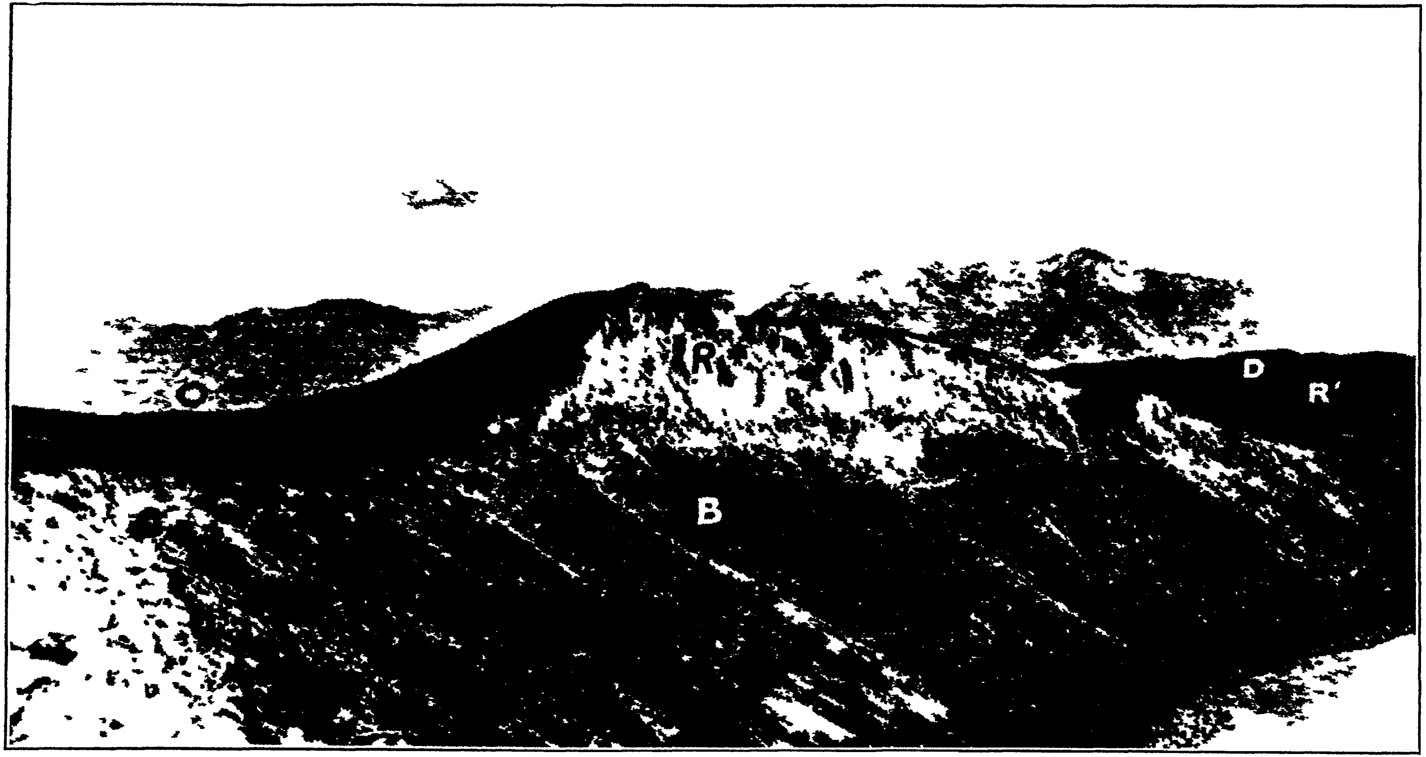
On the eastern bank of the river, the lake-beach is developed close to the outlet, but modified and reduced in height near the downstream end (Plate 8), while behind it, that is, to the east, stretches



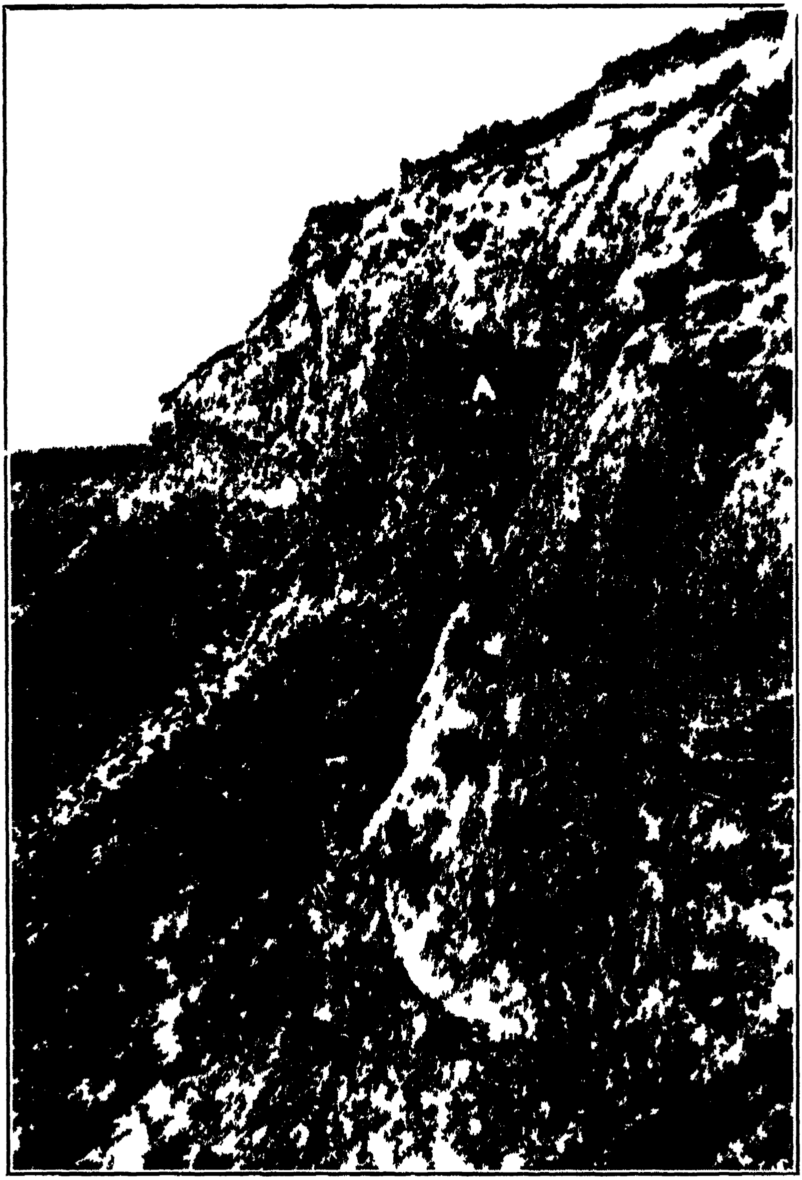
View looking east across the southern end of Lake Pukaki. The middle distance is occupied by the great morainic complex (A). The extension of the ridge with silts to the east of the river is marked by (R), the whole length being shown; the doubtful extension of deposits of the same glacial phase to the north by (R ?). Behind the former and to the right of the latter is the site of the old lateral stream bed, while on the extreme right of the picture the boulder-clay under the moraine shows as a white scar at the top of the river terrace. The seventy foot lake-beach in the foreground is marked (C) and lies on both sides of the road; it shows on the east side of the river near the line of the top of the trees.



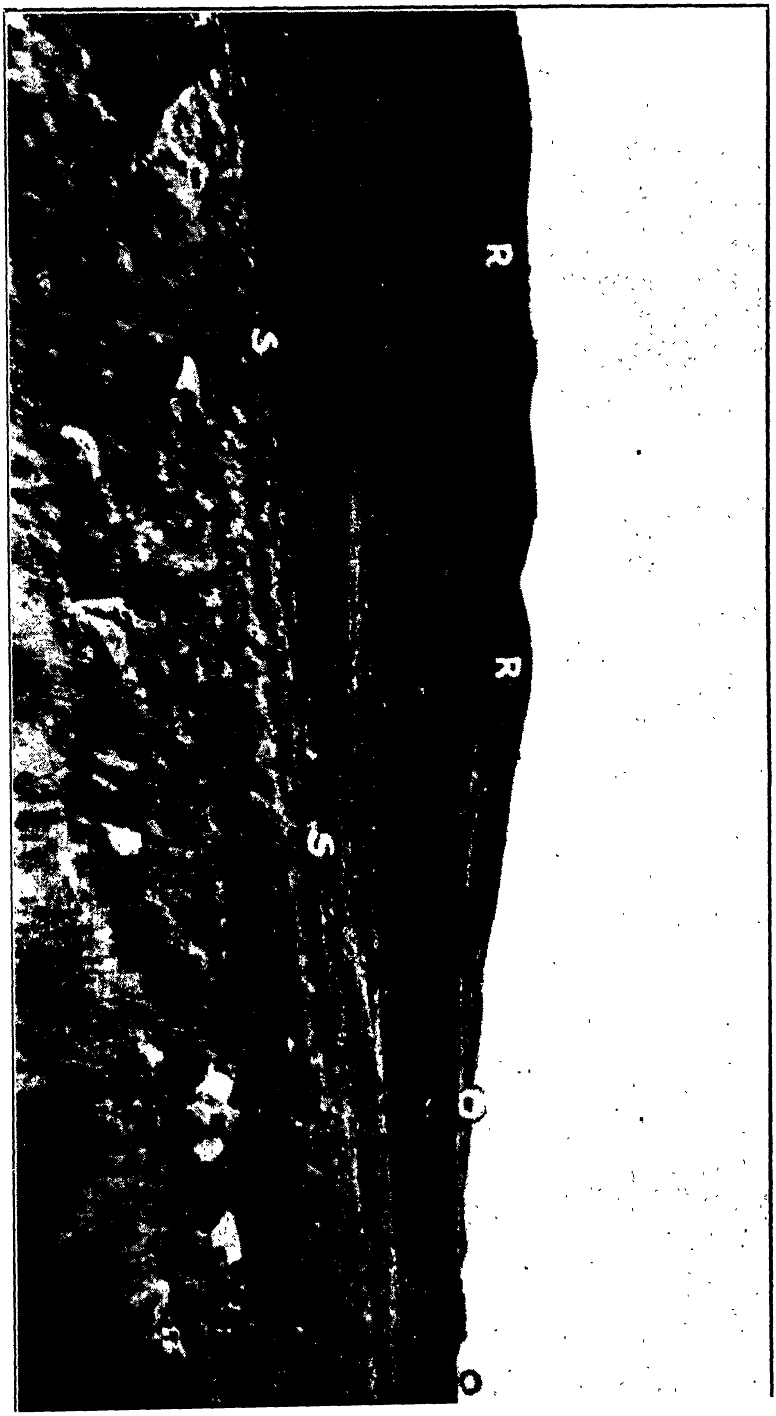
View looking downstream from just below the hotel. The terrace (C) on the left is part of the seventy foot lake beach lowered in level to about sixty feet by river erosion, while the true level of seventy feet appears on the west of the river (C). The cliff ending the ridge (R) shows in the middle distance, and the outwash plain (O) composed of gravels is in the far distance.



Looking upstream towards the river cliff. The outwash plain (O) with occasional boulders is on the left, the tussock covered slopes (B) are probably of gravels the upper levels of which can be faintly seen a little higher than the track. The silt beds marked (R) lie above them. The older morainic complex west of the river can be seen (D) in the distance on the right in front of which lies the extension of the ridge (R′) to the north. The flat terrace mentioned in Section C 4 shows on the extreme right of the picture between the letters D and R′.



Face of the cliff, view looking south. The junction of the gravels with the overlying silt is marked in places by a broken black line. A mass of included gravel with interstratified silt is marked (A) and masses of angular stones are marked (B); included boulders show in the front of the picture.



View looking east from near the road-cutting in boulder-clay and showing the western and central portions of the ridge (R), t surface of the outwash plain lies on the right (O), which has been incised by the stream whose deserted channel (S) shows the foreground.

a detached ridge (Plate 7) with N.–S. orientation, composed apparently of morainic blocks, but evidently a remnant of the ridge west of the river. North of this remnant lies an area of morainic hummocks perhaps dating from the same glacial phase. Behind the ridge fragment stretches an old, deserted stream channel, the counterpart of that west of the river, which joins the present river with marked discordance, and close to the junction a fragment of outwash plain persists at a level accordant with that of the plain west of the river. East of the deserted channel, the ground rises fairly steeply to the summit of the great moraine which in this locality reaches a height of 400 feet above the lake.

At the actual outlet of the lake, the cross-section of the channel of the Pukaki River is open (Plate 7), but this rapidly becomes more confined, and finally the banks are steep and almost precipitous. This is the case where the river cuts through the ridge just mentioned (Plate 8); where it enters the outwash plain, a quarter of a mile from the lake, the bed is deeply incised, 110 feet on the west and 180 feet on the east bank, into the surface of the plain.

C. STRUCTURE OF THE RIDGE. (Plates 8, 9, and 10.)

This ridge resembles a typical moraine in external appearance, and it may be so in general, for large angular blocks lie scattered almost everywhere on its surface, but there are no clear-cut sections except that furnished by the cliff facing the river, and this shows marked departures from the ordinary structure of a moraine; and it is possible that, if other sections could be obtained, additional discrepancies might be observed. As the section of the cliff is most important, it will be described in detail. The sequence exposed is as follows:—

1. *River Gravels.* (Plates 9 and 10.)

These gravels extend from river-level to a height of 110 feet. Their lower slopes are masked with debris, but there is no suggestion that beds other than gravel occur at this horizon. The upper slopes are steep and form the lower members of the actual cliff-face. The clear-cut section here displayed shows that the deposit is composed of subangular and rounded stones in a finer matrix, and with no sign of included morainic material. The uppermost layer, however, contains numerous water-worn blocks, some up to three feet in diameter, and the deposit may be fluvio-glacial in origin. On the cliff-face the upper surface of the gravel appears to be slightly irregular (Plates 9, 10), and near the downstream end it is a few feet higher than the river terrace in close proximity. The material of both shows a close resemblance in texture and composition, and the continuity of the two deposits does not appear to be broken. It is, therefore, reasonable to conclude that, as the gravels under the cliff must have been in position before the overlying beds were laid down, so the gravels of the outwash plain were likewise in position, and any modification they have experienced subsequently is only superficial.

The gravels cannot be traced upstream beyond the face of the cliff, and the beds exposed at a corresponding level are whitish glacial silts very feebly stratified. These appear at various levels down

to that of the river, and they are almost certainly a veneer masking other deposits in this locality. In a trial well sunk near the hotel on the lake-beach, similar silts were passed through, interstratified with rounded stones and angular debris. The gravels do not show for certain on the eastern side of the river near the lake, and higher than the lake-beach in that locality rounded gravels are exposed in a short road-cutting. The exposure is somewhat obscure and they may belong to the boulder-clay to be mentioned later.

2. *Silts, etc.* (Plates 8, 9, and 10.)

These beds form the top portion of the cliff which cuts right across the eastern end of the ridge (Plates 8 and 9). The length of the exposure is about ten chains, the height of the top of the cliff above the river 175 feet, and the maximum thickness of the beds exposed is sixty feet. They consist of stratified silts, somewhat sandy in texture, containing numerous isolated angular boulders, and also lenses and masses of gravel and angular stones usually in a matrix of silt and showing rude stratification. The lines of stratification pass through the gravel with directions corresponding to those of the adjoining silt. At the southern end of the section, the beds have a general synclinal arrangement with minor irregularities; but from about the middle of the exposure they dip upstream and show such distortions as might have been produced by strong local eddies or varying currents operating during deposition. At the extreme northern end of the section, is a small, well-defined syncline in the silts. The inclusions sometimes consist of masses of angular and sub-angular, occasionally scratched, stones, in a matrix of silt, and they thus closely resemble a boulder-clay. They occur at all levels and occasionally rest directly on the surface of the underlying gravels. The finer material has not the tenaciousness of a true boulder-clay, so they were not formed under a glacier in the manner characteristic of such deposits. It is here suggested that they, as well as the silts, were laid down in a lake or large pond lying alongside an ice-face, from which the silts were derived directly as the ice melted, and from which the boulders and other coarser material fell into still, but occasionally strongly agitated, water. The silts occurring at lower levels upstream have apparently no stratigraphical relation to those exposed in the cliff-face. Further west on the ridge exposures are absent; but, judging from the spoil thrown out of the numerous rabbit burrows on the slopes of the ridge, the silty material occurs some distance away from the cliff, though the continuity between the occurrences cannot be established. At the western end of the ridge boulder-clay is exposed in a road-cutting, and it also occurs further west under the cover of the old morainic complex. Both occurrences contain rounded and angular stones, sometimes scratched, and that lying under the western end of the ridge appears to correspond, in stratigraphical position, with the silts exposed at the eastern end, though they may antedate them entirely and belong to the boulder-clay definitely underlying the older moraine further west. It should be noted that similar deposits are exposed on the face of the high terrace on the east side of the river *below the gorge,* and here they lie on gravel and are capped by older moraine.

3. *Moraine.*

This forms a discontinuous capping to the ridge. Blocks lie scattered on the slopes, probably having rolled from a higher level, and they occur on the surface of the outwash plain to the south, becoming scarcer and scarcer as the distance from the ridge increases. They end about half a mile away, but are resumed about three miles downstream, near the old crossing of the river, in a line with the series of dumps mentioned previously. Both these occurrences belong to the earlier complex and do not indicate a former wider extension of the ridge; there is no satisfactory evidence that this ever occurred.

4. *Lake-Beach Deposits.* (Plates 7, 9, and 11.)

Although these deposits have apparently no relation to the problem suggested by the ridge just described, they do deserve some further notice. The chief beach lies at a height of about seventy feet above present lake-level, and another of less importance ten feet higher still. The first has a variable width, sometimes as much as three or four chains, and this suggests a somewhat long period when the level of the lake experienced little change. The higher shelf must be regarded as an ephemeral feature. The tops of both are masked in general by typical beach gravel, on which morainic blocks lie or through which they protrude. Silts appear to be interstratified with the gravels and must have been deposited in a manner similar to that which obtains at present at the southern ends of lakes like Tekapo. The slopes leading down from the main beach occasionally show subordinate shelves, but in some cases they are absent, and this suggests that the lowering of the barrier behind which the lake was ponded was fairly continuous and rapid. It must be noted that the surface of the outwash plain below the ridge lies at a higher level than the main beach, and even than the narrow one ten feet higher, so the gravel of the plain could have functioned as an efficient barrier when the lake stood at its highest level without calling in the aid of moraine as a ponding agent.

A peculiar terrace also occurs on the west side of the lake about half a mile from the outlet, and lying at a height of approximately 165 feet above it (Plate 9). The surface is almost flat and is floored with morainic blocks, though pebbles of typical beach form occur very occasionally, supporting the suggestion that it is a lake terrace. However, it is not clear whether or not it belongs to a higher level of Lake Pukaki, or to a marginal lake ponded between the edge of the ice and the older morainic complex which bounds it on the west. This shelf heads the stream-bed which leads south, outside the ridge, on to the main outwash plain referred to earlier (Plate 11). There are several similar shelves at a fairly accordant level around the lake; but they generally lie in indentations of what would be the former shore-line, had a lake existed at that level; and there is no definite sign of the presence of shelves on the points of a shoreline, where they should have been cut rather than in the sheltered indentations. Therefore I conclude that they are accidental features, or may have been formed in marginal lakes as I have described.

D. Summary of Evidence.

These seem to be the main geological facts on which a discussion of the precise mode of origin of the ridge must be based. It is certainly not a typical terminal moraine taking it as an entity, though sections of it may be classed as such. This applies to the western end and may also apply to that section east of the river. In the case of the former, near the road crossing, morainic material rests directly on boulder-clay, which is what one might expect if it were a typical end moraine, but the cliff-face and, to judge from the rabbit burrows, the central portion also, cannot be explained in this way. The problem therefore is not simple. Although some destruction must have taken place when the river breached the ridge and cut down through the gravels beneath it to present water-level, the form of the ridge does not indicate that it is part of an extensive deposit which has survived erosion, but that its present form closely resembles that which it had originally.

E. Discussion of the Problem.

The special difficulty presented by the case is that of furnishing a satisfactory explanation of the conditions under which the stratified silts, presumably lacustrine, could have been laid down in the apparent absence of any barrier, at present or formerly existing, behind which the water of the lake or pond could have been empounded. The only barriers that the geological circumstances of the locality permit of consideration are (1) *gravel*, (2) *moraine*, (3) *boulder-clay*, and (4) *ice*, and to be an effective ponding agent, the barrier must have reached a height of nearly 200 feet above the present surface of the lake. However, there is no evidence whatsoever for the presence of any of the first three at the necessary height or in the required position. There remains the fourth suggestion, viz., that the barrier was of *ice*, and temporary in character. In this case deposition of the silts could have taken place either in a broad and partially water-filled crevasse near the ice-front, or in a lake lying between the residual of a former ice front and the main body of the glacier. Such a case has been described by Matthes (1940, p. 399) as occurring in connection with the Conness Glacier of the Sierra Nevada. Any silts derived from such a glacier and deposited in the lake would have the features described in Section C, pt. 2, of this article. This suggestion is advanced with all due diffidence and with a full realisation of its uncertain character, but some explanation has to be furnished. It may be commented in this connection that if an adequate barrier, not being of ice, had really existed, why were not the incompetent silt beds removed while it was being destroyed?

Alternatives can no doubt be put forward in opposition to this suggestion, and they include:—

(1) The silts may represent a portion of the surface drift laid down by streams from the ice-front, but their stratification and thickness are against such an explanation.

(2) The ridge might be considered as a normal deposit laid down under the frontal portion of the glacier. This may be correct for the western end, where a veneer of moraine rests on boulder-clay, and perhaps for the portion east of the river, but such an explanation does not fit the case of the deposits exposed in the river-cliff.

(3) The silts could be regarded as a moat deposit, laid down near the ice front, but, as pointed out earlier, there is no indication of a barrier behind which the moat could lie, if ice be ruled out as a possible barrier.

(4) The winding disposition of the ridge and the form of its cross-section suggest that it might be an esker, but the structure as exposed in the cliff, and the orientation of the ridge *across* the valley and not roughly longitudinal with the direction of ice-flow are against such a hypothesis. In neither particular does it resemble the typical eskers of Sweden and Ireland.

So, to sum up, I consider that a portion of the ridge may be explained according to hypothesis (2), but that the position and character of the silts require an explanation similar to that advanced in the first part of this section. The extensions of the ridge northwards on both banks of the river are no doubt latero-terminal moraine perhaps resting in places on boulder-clay.

F. GENERAL SEQUENCE OF EVENTS.

As the area provides evidence of at least two glacier advances, it may not be out of place to give in conclusion a brief summary of the events which took place in the neighbourhood, during and just after, the Pleistocene glaciation. It seems reasonably certain that gravels were in position near Pukaki before the great glacier extension, for they occur under the boulder-clay and moraine on the banks of the river just below the gorge. This agrees with the conclusion arrived at in the case of the analogous Tekapo moraine (Speight, 1940, pp. 183–4), a conclusion supported by Mr. T. G. Beck, Public Works Engineer, in a personal communication. He first of all states that the tunnel at Tekapo, mentioned in my account of the locality as having been driven for a short distance near its outlet in gravel underlying moraine, was continued in gravel under moraine throughout its entire length, and, secondly, he states that a shaft sunk to a depth of 80 feet in order to cut this tunnel near the margin of the lake passed through a thin veneer of moraine, and then through ordinary river gravel, some of it hardly consolidated. These observations give strong support to the hypothesis that gravels, post-dating those correlated with the Kurow Series of Marwick (1935, pp. 329–39) were in position on the floor of the Mackenzie intermont before the deposition of the great morainic complex, and that this complex with its boulder-clay, though reasonably thick, perhaps some hundreds of feet in places, is really only a veneer resting on pre-existent undeformed gravels.

The relations just mentioned are thus analogous to those of similar deposits laid down on the western margin of the Canterbury Plains near the localities where the Rangitata, Rakaia, and Waimakariri Rivers issue from the mountain area east of the main range of the Southern Alps. In these cases moraine forms a veneer over pre-existent gravels, and is not interstratified with them. Further, in only one case that I have observed in connection with the deposits near the mouths of the valleys of the Canterbury rivers, is there evidence that glacial beds were laid down before the deposition of the gravels of which the plains are composed. This occurs at the

lower end of the Rakaia Gorge where, on the south bank, the basal beds are pre-Senonian rhyolite covered unconformably by boulder-clay, fluvio-glacial material, and varved silts in that order. On the north bank of the river, above the rhyolite, there is an obscurity and then 130 feet of silts covered by 200 feet of gravels. Gravels also cover the silts on the south bank, and downstream from the exposure, thick gravel beds occur at a higher altitudinal level than the silts, and may be presumed to be more recent. This evidence seems to be conclusive; but there are difficulties in the way of accepting it at its face value, especially as regards the existence and composition of the barrier behind which the silts were deposited. The only possible barrier appears to have been a mass of pre-existing gravels, and this implies that a considerable deposit of this material must have ante-dated the glacier advance responsible for the formation of the boulder-clay and silts. On the southern bank, too, the section connecting the silts with the gravels downstream is not clear. In the other rivers no similar glacial deposits can be observed to rest on Late Palaeozoic or Mesozoic greywackes where they might reasonably be expected.

Since writing the above, I have received from Dr. C. Caldenius, of Stockholm, Sweden, an account of the Patagonian Shingle Formation (1940) in which he notes (p. 161) that Nordenskjold compared this deposit to the Canterbury Plains. Although the former author was unable to show the relationship of this Patagonian deposit to the Quaternary glacial beds of that region (p. 177), in his summary he assigns the spreading out of the shingle-formation to a climatic deterioration which took place immediately *anterior* to the great Quaternary glaciations. This conclusion as to date agrees with that determined for the gravels of the Mackenzie intermont lying under the moraine, and for those of the Canterbury Plains, provided that in the latter case one can explain the deposition of the varved silts in the Rakaia Gorge as post-dating that of the gravels as a whole or of a considerable thickness of their lower levels. This may present some difficulty, though perhaps not an insuperable one.

After this digression I return to the consideration of the conditions at Pukaki.

As the ice advanced over the gravel substratum near Pukaki, the streams issuing from various sections of the front modified the surface of the outwash plain, not only by adding fluvial material, but also by carrying forward blocks dropped from the ice-front. The possibility that these may have been carried considerable distances renders it difficult to state how far forward the glacier really came, but it certainly reached the series of dumps lying about four miles from the lake shore. During retreat, the outwash plain above the dumps gradually developed, the process continuing while the ice-front was stabilised on or near the line of the great moraine. This plain then reached a mature stage and coalesced in accordant level with that below the dumps, partially overwhelming the latter in the gravel flood. Some, no doubt, were completely covered, a few to be brought to light when the Pukaki River incised its bed into the plain at a later date. During this period the surface of the plain took its present form, and its maturity of development indicates that considerable time elapsed while the ice was retreating from the line

of dumps to that of the main moraine, and while the ice-front was stabilised in that position. The enormous mass of material constituting this feature also implies a relative stability of front or but slight variation therefrom for a long period.

This stability was followed by retreat when the gap was opened near the south-western corner of the lake, through which the concentrated drainage of the Tasman-Pukaki valley and its tributaries discharged. It is possible, too, that a lake was then in existence during this episode, and the conditions may have resembled those now existing. Additional gravels would be laid down on the outwash plain, building up its surface further and extending upstream through the jaws of the gap. The ice advanced again and was in some way responsible for the formation of the ridge under special consideration. Whether this advance was a mere modification of the ice-front, or a second glacial episode of major importance, cannot be stated; but the width of the gap suggests that a considerable interval of time elapsed between the formation of the complex and the ridge. If the circumstance is of major importance it adds another to the critical events of the Pleistocene Glaciation. It has been maintained (Speight, *op. cit.*, p. 180) that the cross-section of the Tasman Valley indicates that there were two periods of glacier advance, the great moraine at Pukaki belonging to the latter. So, if another is added, there may have been three distinct phases of the Pleistocene Glaciation of the region, and if the line of dumps previously referred to is of major importance, there may be yet another.

After the formation of the ridge at Pukaki, a retreat of the glacier occurred once more, and the hollow behind the ridge and the older complex was occupied by a lake whose surface, for a comparatively short period, lay eighty feet above the present lake level. It then fell some ten feet, when a broad persistent beach was formed, and then it fell gradually to what it stands at now. The surface of this lake does not appear ever to have reached the level of the uppermost gravels under the ridge, or the surface of the plain just in front of it, so the gravels functioned as the barrier behind which the lake was ponded, moraine playing a relatively unimportant part in its formation. The cutting down of the gravel barrier and the formation of the gorge of the river were no doubt responsible for the fall in level of the lake. Downstream the plain is deeply terraced, but the terraces gradually decrease in height till they disappear as such and merge into the general surface of the plain, which at this stage is being aggraded, not only by the Pukaki, but also by the Tekapo and Ohau Rivers, before they unite to form the Waitaki River and to cut the deep, rock-bound gorge through the mountains which rim the intermont on its southern margin.

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A New Species of *Onychiurus* (Collembola) from New Zealand.

By J. T. Salmon, M.Sc.
Entomologist, Dominion Museum, Wellington.

[*Read before the Wellington Branch, April 22, 1942; received by the Editor, April 23, 1942; issued separately, September, 1942.*]

Family ONYCHIURIDAE Lubbock, 1867.

Sub-family Onychiurinae Börner, 1906; Bagnall, 1935.

Genus Onychiurus Gervais, 1841.

Onychiurus novae-zealandiae sp.nov. Plate 12, figs. 1–7.

Colour: A uniform creamy white.

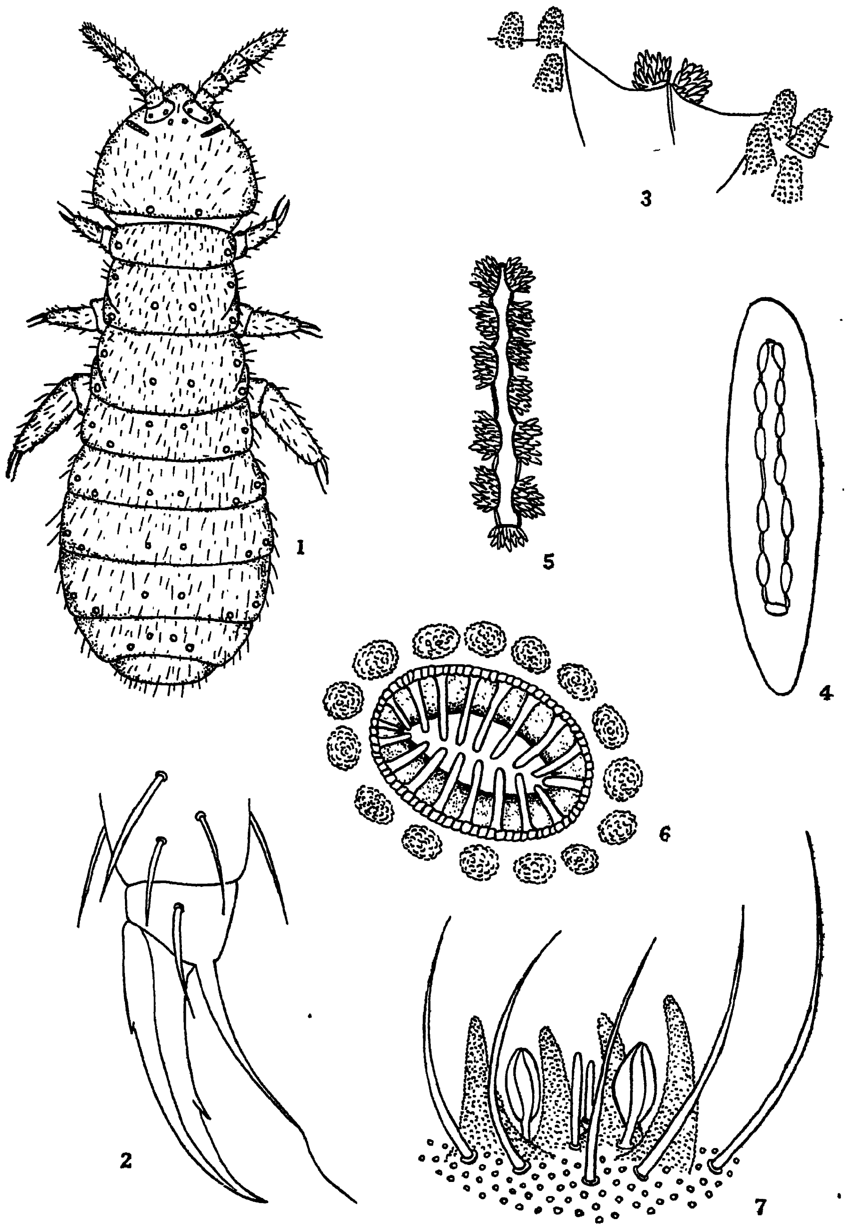
Body: Length up to 1·8 mm. Evenly clothed with very short, and moderately short, plain setae; the latter 2–3 times as long as the former. Cuticle finely tuberculate with the tubercles themselves finely granulate. Antennae shorter than the head in length, the relative proportions of the four segments being as 12 : 20 : 21 : 36–46. Sensory organ on Ant. III with four granulate cones, two plain central sense rods, two smooth sense clubs, one to each side, and five guard setae; the whole situated behind a low integumentary fold. There is a small sensory fold just below the tip of Ant. IV. Antennae with numerous short curved sensory setae, especially towards the apex. Postantennal organ consisting superficially of 10–15 small lobes, but the deeper structure is made up of 10–15 groups of tubercles joined in a chain around the summit of a prominent ridge which itself arises from the floor of a deep and wide groove. Pseudocelli are present as follows: Three at the base of each antenna, arranged in the form of a right-angled triangle, with the right angle on the inner anterior corner and the long side of the triangle running outward, two of these pseudocelli are on the antennal base and the third is just off it; one to each side of the posterior margin of the head; Th. I one to each side; Th. II and Th. III each with two centre-dorsal and two to each side, in the latter of which in each case one is anterior to the other; Abds. I, II, III, and IV each with two centre-dorsal and two to each side, the latter arranged obliquely; Abd. V with four centre-dorsal arranged as two oblique pairs; Abd. VI without pseudocelli. Anal spines absent. Ventral tube small.

Legs: Claw with one distinct tooth just past halfway down inner margin and two small outer lateral teeth, one to each side, at about one-third down. Empodial appendage needle-like, reaching to beyond inner tooth and projecting into a thin wavy filament which reaches beyond the apex of the claw. Tenent hairs absent.

Furcula: Absent.

Locality: Buller's Bush, Levin, amongst leaf mould on bush floor; very common. Author's collection.

Type: Slide 3/1174 and Figured Paratypes slides 3/1175–6, Dominion Museum collection.



FIGS. 1–7—*Onychiurus novae-zealandiae* sp. nov. FIG. 1—Whole insect, × 40. FIG. 2—Foot claw. FIG. 3—Postantennal organ, end view to show groove and ridge. FIG. 4—Postantennal organ, superficial appearance. FIG. 5—Postantennal organ, detailed structure. FIG. 6—Pseudocellus. FIG. 7—Sensory organ from Ant. III.

Remarks: This species is closest related to *O. subcadaverinus* Denis from Costa Rica; *O. novae-zealandiae* differing from *subcadaverinus* principally in the number and arrangement of the pseudocelli. In *O. subcadaverinus* there are two pseudocelli on each side of the posterior margin of the head, none on Th. I, and only one lateral pseudocellus on each of Th. II and III and Abds. I–IV, while Abd. V has two. The New Zealand species is also, on the average, smaller, and has the postantennal organ more complicated than the Costa Rican species.

The occurrence of an indigenous species of *Onychiurus* in New Zealand is particularly interesting, as it supports the view which I put forward previously, that the cosmopolitan species of *Onychiurus* occurring in New Zealand were not necessarily introduced after European settlement began, but are part of an archaic element which reached New Zealand in early geological times (*Trans. Roy. Soc. N.Z.*, vol. 70, pp. 420–426). The fact that the nearest related form occurs in South America is interesting as affording further evidence for closer zoogeographical relationship between New Zealand and that country, a relationship which in the Collembola is particularly weak.

Buller's Bush, the only locality at present known for this species, is the isolated remains of a once very extensive lowland forest. It is possible that *O. novae-zealandiae* in the past enjoyed a very much wider range of distribution and may yet be found in other areas of the North Island, particularly in the gorges leading into the Tararua Ranges.

The Basic Igneous Rocks of Eastern Otago and Their Tectonic Environment, Part III.

THE OLIVINE THERALITE OF WAIHOLA, EAST OTAGO, A GRAVITATIONALLY-DIFFERENTIATED SILL, WITH NOTES ON RELATED ROCKS.

By W. N. Benson.

Including Appendices by F. J. Turner and C. O. Hutton and Chemical Analyses by F. T. Seelye.

[*Read before the Otago Branch, November 20, 1941; received by the Editor, November 27, 1942; issued separately, September, 1942.*]

General Geology and Petrology.

In 1911 J. P. Smith discovered on the western shore of Lake Waihola, twenty miles south-west of Dunedin, a basic nepheline-rich rock, comparable with one labelled "Diorite, Lake Waihola," which had been placed in the Otago Museum by Professor F. W. Hutton some time before 1879. Subsequently, in company with Mr. Smith, Dr. Marshall examined it in the field, and wrote an account thereof, and of other nepheline-rich rocks in the outskirts of the Dunedin district, and of one found near Auckland (Marshall, 1912). The mode of occurrence of the Waihola rock was left uncertain, and is described in the present paper. A number of allied rocks have now been found, and their varied petrographical features have been studied, the investigation being greatly helped by universal stage measurements by Dr. F. J. Turner, recorded in an appendix hereto. Dr. C. O. Hutton has made centrifuge-separations of a titanaugite and a zeolite from one of the rocks, has determined their optical properties and densities, and has discussed their compositions in a second appendix. Through the courtesy of the Director of the Geological Survey and the Dominion Analyst, analyses of these two minerals together with two complete rock-analyses have been made by Mr. F. T. Seelye. To these gentlemen the writer's most cordial thanks are due.

The boundary of the igneous rocks west of Lake Waihola, as sketched in the maps of Marshall (*op. cit.*) and of Ongley (1939), needs some modification, and this, together with the boundaries of their subdivisions, are shown on Fig. 1. The basement rock is the prevalent quartz-albite-muscovite-chlorite-epidote-schist of about the Chl. 3 stage as recognised by Dr. Turner (1940). On a peneplain cut in this in Cretaceous times there rests a westward-tapering wedge of sediments comprising a few feet of Upper Cretaceous coal-measure sandstone followed by 60–100 feet of very Late Cretaceous glauconitic Abbotsford mudstone, both of which formations are closely similar to their equivalents in the Dunedin district, wherein evidence of their age has been obtained (Ongley, 1939). The glauconitic mudstone is

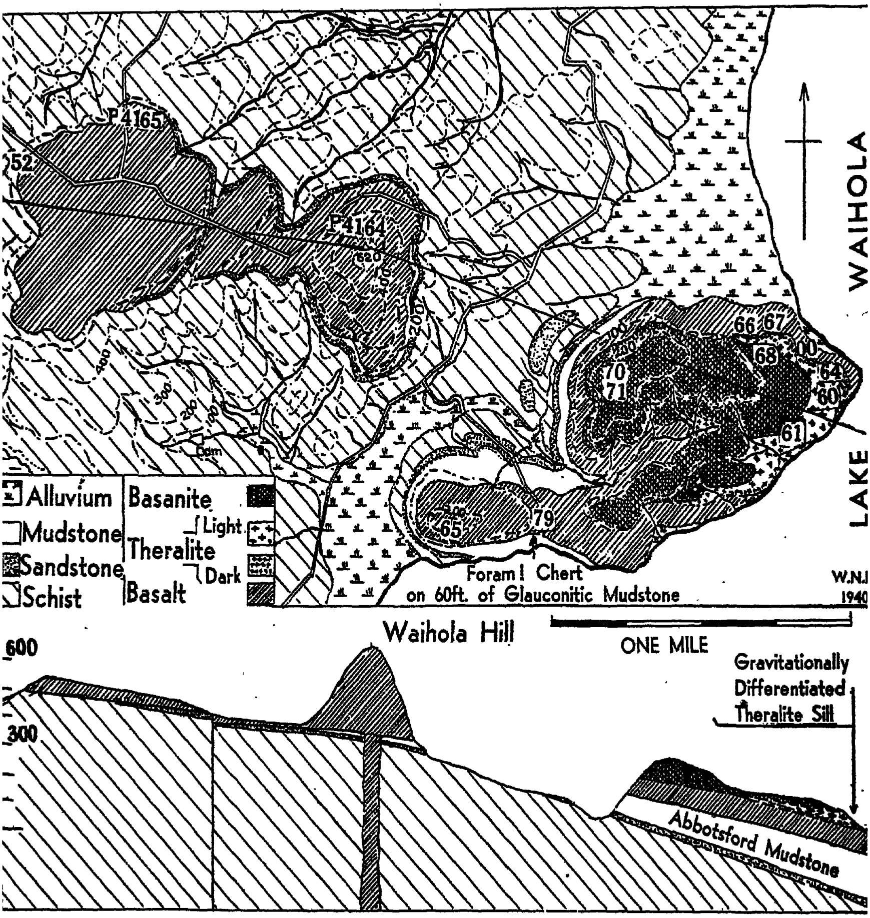


Fig. 1

best exposed in a steep cliff rising from the lake-shore beneath the southern margin of the igneous rocks, and is here capped by a formation without known analogy in Eastern Otago, a yellow-buff chert of small extent and about three feet thick lying immediately below the lava. Though apparently homogeneous in hand-specimen it shows in microscopical section remains of the stem of a large brown fucoid like *Durvillea** and numerous indeterminate foraminifera. In Late Tertiary times the area here described was tilted eastward, and a second peneplain was cut, passing westward obliquely from the chert and mudstone on to the schist. The igneous rocks which rest on this erosion-surface were erupted probably during the late Pliocene times. Three groups of rocks may be recognised among them.

The earliest and most widespread is an olivine basalt, represented by slides P.4164–5, cut from material collected for the Geological

* For this comparison we are indebted to Dr. J. E. Holloway.

Survey by Ongley, and by 5052, 5065, and 5079 in the Otago University Geological Museum. The positions of these are shown in the accompanying map (Fig. 1), the last two digits only being given for the University slides. The flow was erupted probably from beneath Waihola Hill, where it is about 300 ft. thick, but east and west thereof it extends as a sheet less than 100 ft. thick. The rock, which has a specific gravity of 3·00, is an almost normal fine-grained basalt with a minor proportion of small olivine phenocrysts, though on the summit of Waihola Hill, a small amount of zeolite is present, and the rock begins to show something of the characters of the earliest zeolitic basalt in the Clarendon-Milburn district four miles further south, described in detail elsewhere (Marshall, 1912; Benson, 1942), though it is not to be correlated therewith. The overlying flow of basanite (atlantite) rests directly on the basalt on the landward side of the promontory, but further east the flows are separated by the intervening theralite sill. The higher flow (5070, 5071) is very distinctive both in hand-specimen and under the microscope. It is dense (sp. gr. 3·06), and contains abundant phenocrysts of olivine and subordinate titanaugite, and seriate phenocrysts of labradorite, set in a fine-grained basaltic matrix. In this matrix there is a rather uneven distribution of the dark minerals (minutely prismatic and granular titanaugite and titaniferous magnetite), while a little analcite and an indeterminate, birefringent zeolite occur both interstitially and in small, irregular, micropegmatoid patches associated with rare small patches of irregularly granular or poikilitic nepheline and labradorite containing idiomorphic titanaugite, and also with little segregations of sanidine and minute flakes of biotite. Xenoliths of quartzose schist show the replacement of chlorite and epidote by small augite prisms, and many xenocrysts of quartz illustrate all stages in the development of a finely granular, pyroxenic reaction-rim up to complete replacement of the quartz by more or less ovoid aggregates of minute augite granules. Rarely xenocrystic picotite is present.

Appearing from beneath this upper flow and extending eastward to the point of the promontory, is the wedge-like sheet of more or less coarsely granular rocks containing those which Marshall (1912) described. Exposures are poor, but there can be little doubt that this westward tapering sheet is intrusive and dips eastward at about 5°, reaches a maximum thickness of rather more than fifty feet, covers in all about a hundred acres above lake-level, and extends for some distance eastward beneath the lake. Its lower portion is best studied along its north-eastern margin, where, immediately above the basalt, is a ledge in which there occur, both *in situ* and as loose blocks, many exposed masses of a rather fine- to medium-grained melanocratic rock with a specific gravity of about 3·00. Such rocks, and the top of the underlying basalt, may be traced down to the water's edge at the end of the promontory. Immediately above them the loose rocks have a rather coarser grain-size, are lighter in colour, and less dense (sp. gr. about 2·9). What must be near the top of the sill is exposed, in deeply weathered form, in a low cliff, and in several immense isolated blocks about 600 yards south-west of the point. This is a very coarse and meso-leucocratic rock with a specific gravity of 2·8–2·75,

the lower figure being given by the most strongly zeolitic and slightly drusy specimens. The rock may be traced by loose blocks about fifty yards westward up the grassy slope, until blocks of the covering basanite are encountered. No evidence was obtained of the presence of an intervening upper melanocratic layer of the coarsely granular rock. The southern margin of the intrusion is more obscured by soil-drift, though dark coarse-grained loose blocks occur here and there. The western development at the head of the small valley is wholly under ploughed land, and the loose blocks therefrom have been collected to form stone fences.

The general features of the rocks in this sill are illustrated in Fig. 2, with the proviso that as each micro-drawing is of a field selected to show the structural relations of as many minerals as possible, it is not also representative of their relative abundance. Thus 5061 of Fig. 2 is structurally typical of those rocks of the upper portion of the sill which contain relatively little zeolite, though the field of view chosen for illustration is rather unusually rich in dark-coloured constituents. Except for the scarcity of zeolites 5067 is very typical of the bulk of the moderately coarse and not strongly melanocratic rocks in the lower portion of the sill, while 5064 represents the least coarsely granular and most basic rock occurring in small amounts near the base of the sill in its north-eastern exposure. The source of 5699 is not known. The specimen bears only the locality "Waihola" in Smith's handwriting. The petrographic features, however, suggest it also was obtained from near the base of the sill. The locality from which Marshall collected the meso-leucocratic and richly zeolitic specimen 5698 was almost certainly near the top of the sill.

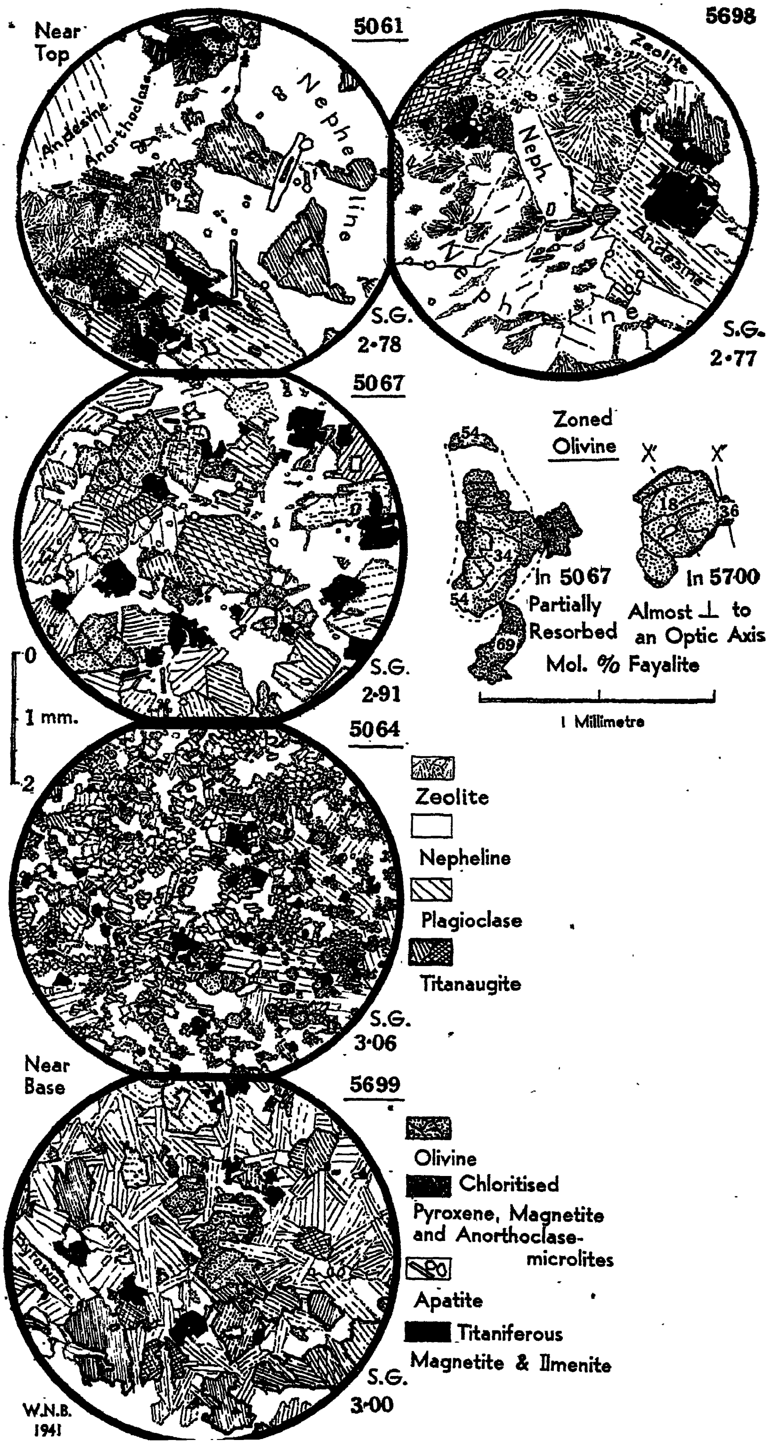
The rocks of intermediate character are represented by the analysed and figured specimen 5067 (sp. gr. 2·910). It contains more or less idiomorphic or occasionally sub-ophitic crystals of titanaugite up to 3·0 mm. across. They are associated with iron ores and apatite, and rarely show a tendency to be moulded against the plagioclase or to fray out into sub-graphic intergrowth with nepheline. They have a zoned or hour-glass structure. The inner portion, usually displaying a lighter colour than the margin, has a larger optic axial angle ($2V=(+)64°–47°$) than that of the broad outer zone ($2V=(+)54°–42°$), from which it is usually separated by a sharply marked but irregular line. This angle then increases quickly to $2V=(+)72°$ in a thin greenish outermost zone. The extinction-angle ($Z \wedge c=46°–53°$), in the absence of salite structure or twinning, cannot be read without a possible error of about $3° \pm$. It is rather large in all parts of the crystal. From the diagram given by Deer and Wager (1938, p. 22) it may be inferred that the high values of $Z \wedge c$ for crystals having $2V=(+)45°–50°$ betoken a general richness in iron, and that the cores of the crystals of titanaugite in 5067 have compositions lying on the boundary between diopside and hedenbergite. The outer zone, though less calcic, is still rich in $FeSiO_3$, and the change of colour and increase in optic axial angle in the outermost portion accompany the entry of the acmite molecule into the composition of the pyroxene. In these greenish mantles finely granular magnetite is abundant, though but little occurs in the purplish pyroxene.

The olivine may show a zoning marked by variation in birefringence, of extinction-angle in oblique sections, and of optical axial angle, indicating an outward increase in the proportion of fayalite as described by Tomkieff (1939). A strikingly zoned crystal in 5067 (see Fig. 2) shows a variation of axial angle indicating that a central portion of composition Fa_{84} has an outer zone of Fa_{56} beyond which, but still in optical continuity with it, are outlying remnants of an almost completely resorbed mantling zone of Fa_{69}. The particular grain figured does not, however, lie in such a position as to display a zonal change of extinction-direction or birefringence.

The feldspar is in more or less idiomorphic tabulae, approximately 1·5×0·2 mm., flattened parallel to 010, elongated parallel to *c* and partially replaced by zeolite, which has formed in cracks traversing the feldspar. It includes both potassic feldspar and plagioclase (An_{38}). The former has 2V=(—)45°, the optic axial plane being perpendicular to 010, and according to Spencer's (1937) data, might be either orthoclase or more probably anorthoclase rich in soda. This uncertainty, together with the impossibility of determining the composition of many of the grains of pyroxene or of feldspar, and the difficulties introduced by the development of zeolite, discourages the use of Rosiwal's method for estimating quantitatively anything more than the general proportion existing between several rather heterogeneous groups of minerals (cf. Smith and Chubb, 1927).

Nepheline was the last anhydrous mineral to crystallise and formed a matrix of poikilitic grains often over 10 mm. in diameter. Like the nepheline in the nephelinite of Lake Kivu, Africa (Shand, 1939), that in the Waihola complex is unzoned. Its refractive indices are only very slightly less than that of Canada balsam. The analysis of the rock as a whole suggests that it is probably a potassic type. It is partially replaced by zeolite, the fibres of which have positive elongation (but see p. 181). This occurs in irregular marginal or interstitial patches or in the cracks, which traverse the mineral in many directions. Iron ores more or less idiomorphic and including both titaniferous* magnetite, and ilmenite and also apatite are abundant accessories. The last mineral forms prisms up to 2·0 × 0·15 mm. long and thick, embedded in all the other constituents, but though it was thus the first mineral to commence crystallising, it seems to have continued to form during most of the period of rock-consolidation, for it often projects from the coarse-grained material into the interstitial patches of finely crystalline material in which it is often more abundant than elsewhere, just as was noted by Tyrrell (1928) among analogous rocks in Ayrshire (cf. also Elsden, 1908, pp. 289–290). In this rock, as in most of the other Waihola theralites here described, the apatites contain inclusions, often filled with liquid. These are not swarming minute objects elongated parallel to the vertical axis of their host, such as darken the larger chiefly xenocrystic apatite-prisms in many Dunedin rocks: usually a single tube only occurs about 0·01 (rarely 0·02 mm.) in width extending in the above direction for the greater part of the length of the crystal. In this tube is mineral-matter seemingly in part of a composition related to

* Confirmed by magnetic separation and chemical test for TiO_2.



Near Top
5061
Andesine
Anorthoclase
Nepheline
S.G. 2·78
5698
Zeolite
Neph.
Nepheline
Andesine
S.G. 2·77
5067
S.G. 2·91
Zoned Olivine
54
34
54
69
In 5067 Partially Resorbed
X′
X′
18
36
In 5700 Almost ⊥ to an Optic Axis
Mol. % Fayalite
1 Millimetre
0
1 mm.
2
5064
S.G. 3·06
Zeolite
Nepheline
Plagioclase
Titanaugite
Near Base
5699
Bytownite
S.G. 3·00
Olivine
Chloritised Pyroxene, Magnetite and Anorthoclase-microlites
Apatite
Titaniferous Magnetite & Ilmenite
W.N.B. 1941

has formed in the cracks of this olivine. The crystals of pyroxene, which may be over 4 mm. long, have usually a dark purple zone with $2V=(+)44°–48°$ and slight axial dispersion surrounding a paler purplish brown more diopsidic core with $2V=(+)50°–54°$ and strong axial dispersion, though in a few crystals paler material may occur outside the darker. In either case a greenish border with $2V=(+)58°$ expresses the entry of the acmite molecule in notable amount into the construction of the pyroxene. Such material may fray out into fine greyish to bright green intergrowths with feldspar or be rarely moulded thereon, or even on the nepheline in rocks such as 5061 and 5698 in which this mineral is very abundant and idiomorphic. (See Fig. 2.) The feldspar occurs in large irregular prismoid grains, occasionally over 6 mm. long. As Marshall (1912) noted, " it is much twinned on the albite and pericline laws, and has in many places the appearance of microcline. The extinction-angle, however, proves it to be andesine." Two universal stage measurements give An_{39}. In some cases it is surrounded by a thick outer zone of anorthoclase sharing the (010) and pericline twinning-planes in common with the plagioclase. Nepheline forms large more or less irregular to subidiomorphic grains in 5060 and 5061, but in 5698, in which it is the dominant mineral, it crystallised before the feldspar forming short idiomorphic prisms over 1·0 mm. thick against which the feldspar and sodic pyroxene may be moulded. Rarely, as in 5061, subidiomorphic nepheline prisms are enclosed in purple titanaugite. Complete replacement of idiomorphic nepheline has given rise to pseudomorphs in which the deuteric zeolite is commonly present as irregularly dispersed and bounded aggregates of radiating fibres, which, when viewed in a direction perpendicular to the basal plane of the original nepheline, may be seen in places to be grouped into several sets of thin prisms (possibly perpendicular respectively to the prism faces of the nepheline), the several sets being arranged in stellate fashion and occupying definitely limited sectors of the pseudomorph. (See Fig. 2). The irregular patches of residual material are generally less finely granular than in the melanocratic rocks. They contain apatite prisms $1·2\times0·08$ mm. with the characteristics already described. Anorthoclase ranges in form from nearly rectangular laths up to $0·6\times0·05$ mm. to less sharply bounded, narrow laths at most 0·5 mm. long and thence down to minute more or less curved microlites. Between these is a mixture consisting of pale to dark gren or greenish-brown chloritic material, and little flakes of deep brown biotite, apparently developed by reaction between the alkaline residual liquid and the iron ores, about which they may be wrapped, though they also occur separately and are occasionally moulded on the ends of the feldspar microlites. Between these is a matrix of zeolite, either clear or slightly stained by chlorite or limonite, or turbid, perhaps through partial dehydration during the making of the rock-section. In some specimens (e.g., 5061) the zeolite forms rather large patches (4×2 mm.) from which the central portion has been removed, so that the rock appears slightly drusy.

In the rock-sections, the thin prisms of zeolite usually show a positive elongation, a birefringence slightly greater than that of the adjacent plagioclase, and an optic axial angle as measured in a number of crystals approximately $2V=60°\pm5°$. Occasionally,

however, a zeolite, not otherwise distinguishable from these, shows $2V=30°$. In rare cases different sectors of a fibrous radiating zeolite may show either a positive or negative elongation (but see p. 181), indicating that it is probably a thomsonite. In order to determine in more detail the composition of the zeolite in a typical and abundant richly sialic rock, Dr. C. O. Hutton, at the writer's request, very kindly separated the zeolite out of 5698, and his observations recorded in Appendix II, confirm the thomsonitic nature of the zeolite, but indicate that it is a very abnormal, if not hitherto quite unrecorded, markedly potassic type. The opportunity was taken while making this separtion to obtain and determine the composition and other properties of the titaniferous augite in this rock, and the refractive indices and density of the apatite which are also recorded in Appendix II.

The deuteric processes in these rocks are:—

(a) The more or less advanced zeolitisation of feldspar and especially of the nepheline. The process works inward from crevices and may result in the complete and sometimes pseudomorphous replacement of the nepheline with occasionally (as above) partial removal of its substance, leaving a small cavity with resultant lowering of the density.

(b) The formation of scraps of biotite by the action of the residual alkaline liquid on the iron ores.

(c) Incipient chloritisation of the late-formed pyroxene.

(d) Formation of golden-brown iddingsite, the alteration product of the olivine when acted upon by the residual liquid, sometimes associated with a little bowlingite, which may be a still later product.

The whole association of rocks affords in miniature a vivid picture of the processes attending the consolidation of an aqueous basic alkaline magma, differing in some respects from the rather similar though not identical rock-associations in Utah, Ayrshire, and Shiant described by Gillūly (1927), Tyrrell (1928) and Walker (1930) respectively. Apatite was the first mineral to commence crystallisation. The formation of the iron ores followed, shortly to be succeeded by the separation of very calcic plagioclase (anorthite-bytownite). Then forsteritic olivine (about Fa_{33}) commenced to separate and, though more magnesian than the olivine which formed later, its rather high content of fayalite reflects the abnormally ferruginous character of the parent-magma, one of the distinctive features of the basaltic rocks of the Dunedin district (see Benson and Turner, 1940, p. 58). That some concentration of iron had occurred in the initial segregation of the theralite magma from the parent reservoir is suggested by the generally smaller content of fayalite (averaging Fa_{21}) in the early formed olivines in the basalts of the Dunedin district (Benson and Turner, 1940, p. 67). Separation of titanaugite, again rather unusually ferruginous, commenced after that of olivine and both of these mafic silicates as they grew included ophitically tabulae of the still very calcic plagioclase, and began to sink into the lower parts of the intrusive sheet of magma, where from the residual magma there formed less calcic outer zones about such feldspar crystals as were free to react with it, together

with a subordinate amount of nepheline which was rather uneven in its distribution (e.g., 5699). This early separation left a melt rather impoverished in lime and magnesia. Of the crystals suspended therein, the olivine received outer zones which were increasingly ferruginous, up to Fa_{65} or more, or grains of like composition formed about new nuclei, and both were in their turn more or less resorbed probably during the later stages of pyroxene-formation. A slightly less calcic but still rather ferruginous titanaugite formed about the earlier crystallised more calcic-hedenbergitic grains, and ultimately merged outwards into greyish to bright green aegirine-augite, forming a mantling zone containing abundant finely granular magnetite as the residual magma became enriched in both alkalies and iron. At this time also some resorption of the fayalitic outer zones of the olivines may have occurred and the plagioclase was made over into a probably rather potassic andesine, and continued to grow with that composition. It was at this time no longer idiomorphic but was moulded against the olivine and pyroxene. In contrast with the sequence of mineral formations in the analogous complexes in Scotland and Utah, no plagioclase more sodic than andesine has been found in the Waihola complex. Nepheline, probably more potassic than before, and still the last of the principal colourless minerals to form, made irregular poikilitic grains extending in optical continuity for several millimetres.

As crystallisation advanced towards its close, the increasing concentration of potash in the residual magma was expressed in two ways. Microlites of anorthoclase (together with finely granular interstitial aegirine-augite, apatite and iron ores) crystallised in irregular patches among the larger crystals in ever-increasing amount and grain-size. In addition, the tendency for potash-feldspar to remain in strained isomorphism with the plagioclase crystals gave way with decreasing temperature to the separation of anorthoclase forming thick zones about the plagioclase grains. With its formation and consequent discharge of accumulated potash from the magma there may have been a renewed concentration of soda in the melt, so that potassic (?) nepheline became the most abundant anhydrous product, and where this is the case its period of crystallisation was advanced until it largely preceded that of the feldspar. On the other hand, in alkaline melts which had been developed in the upper portion of the sill the period of separation of pyroxene was extended by the entry of the acmite molecule into its constitution, and the latest crystallisation of pyroxene either accompanied or followed both that of the nepheline and of the plagioclase. The texture and increased grain-size of such rocks approach that characteristic of pegmatite, though they must have consolidated under a cover of basalt at most only a few hundred feet thick. The relatively rapid cooling, however, prevented the coarsely granular texture from extending throughout the whole of the complex. In every part of it (except perhaps the lowest portion composed in large part of gravitationally accumulated crystals), a residual more or less aqueous magma consolidated as aggregates of microlitic anorthoclase with apatite prisms, interstitial aegirine-augite, and minutely granular iron ores. Meanwhile the effect of the increasing concentration of water in the melt was seen

in the conversion of some olivine into iddingsite as the concentration of iron increased and the temperature fell, a deduction in full accord with Edwards' (1938, p. 486, 1938a, p. 280) view that "it is essential for the formation of iddingsite that the magma should be not only rich in water vapour, but that it should have differentiated in such a way as to give rise to an iron-rich fluid." The formation of bowlingite rather than iddingsite from the residual olivine was probably a still later deuteric process. The partial chloritisation of the minutely granular pyroxene in the interstitial patches may be assigned to the same cause, and so, also, because of the alkalinity of the residual melt, the formation of the rare scraps of deuteric biotite in the most alkaline rocks. That small amounts of carbonates (calcite, etc.) occur in certain of the Waihola theralites, not in direct association with these residual patches or with the masses of zeolitic material, leaves in doubt the decision as to whether their formation preceded or followed the more explicitly deuteric processes. The features of the associated volcanic rocks seem, however, to be consistent with the view that all these processes may have been more or less contemporaneous.

The deuteric formation of zeolite was most advanced in the more highly alkaline upper portions of the complex, but all of them are affected by the process. None of the rocks so far investigated appears to afford evidence of the formation of any analcite, such as occurs in the rocks of the other complexes already cited, nor of any other zeolite by primary crystallisation, i.e., during or before the crystallisation of any of the anhydrous rock-forming minerals. On the contrary the zeolite everywhere replaces nepheline, or to a smaller extent feldspar. The reason for this contrast is not apparent at present. It is not possible to detect any difference in composition between the zeolites replacing nepheline and those replacing the feldspar. The average composition of the secondary zeolite has been shown to approximate to that of a potassic thomsonite. (See Appendix II.)

Discussing the origin of a series of rocks comparable to some extent with those herein described and the others to which comparative references have been made, Drescher and Krueger (1928) concluded that after the continuance of formation of anorthoclase down to an assumed temperature of 400° C., zeolitisation supervened, commencing at about 350° C. and continuing as the temperature fell to about 90°. They pointed out that had a concentration of potash preceded that of soda, myrmekite and checker-board albite might have replaced the anorthoclase, but that with such a mineral sequence as occurs in our rocks, namely, CaNa→K→Na, the temperature at the time of the second concentration of soda had been lowered to such an extent that this form of replacement, though very common in pegmatites, could not here take place. It is, therefore, uncertain to what extent the greater volatility of compounds of potassium than those of sodium, to which Bowen (1933) refers, may be responsible for the increasingly sodic character of the residual magma at this late stage.

It is interesting to recall the experiments cited by Morey and Ingerson (1937) which bear on the conditions of origin of the late-

formed minerals in the Waihola complex. Thus Thugutt (1894–5)* obtained from nepheline attacked by K_2CO_3 solution at 200° C. a potassic natrolite readily converted to the sodic mineral by heating with Na_2CO_3 on a steam bath. Doelter (1906)* found that analcite would crystallise at temperatures between 400° C. and 190° C. from a variety of solutions of analcite and natrolite; also that natrolite would form from similar solutions at temperatures between 190° and 90°. Koenigsberger and Müller (1906)*, moreover, obtained anorthoclase as a result of the attack of water on alkaline glass at 360°. Less significant for our problem was the work of Friedel (1912)*, who obtained a little natrolite from the attack of aqueous solutions of KOH on mica at temperatures as high as 510°–600°, and of Gruner (1929)*, who found natrolite to crystallise freely when muscovite or paragonite were attacked by aqueous solutions of KOH and NaOH especially at 400° C., but also at lower temperatures.

The above descriptions of the rocks in the Waihola complex raise the question of nomenclature. The term nephelinite originally applied to them seems inappropriate in view of the abundance of feldspar in all of the members of the complex, which would bring them much closer to the scope of Rosenbusch–Osann's (1922) latest definition of theralite as hypautomorphic granular rocks consisting of abundant or predominating pyroxene together with lime-soda plagioclase, nepheline and possibly sodalite with accidental or accessory biotite, hornblende, olivine, iron-ores and apatite. Lacroix (1920) added that orthoclase in these rocks should be rare or concealed. Its presence at all, Johannsen (1938, p. 222) holds, would exclude the rocks from the strictly Rosenbuschian theralite, though Rosenbusch himself (1907, p. 428) notes its occurrence forming a shell around the plagioclase crystals in the material from Duppau, Bohemia, which he describes most carefully as a type of the rock-species. The plagioclase should be decidedly basic and dominant over the nepheline. Lacroix (1920) recognised two distinct varieties of theralite, beronditès characterised by the presence of brown hornblende, and luscladites in which olivine accompanies the pyroxene. His typical luscladite had a hyperitic structure and only a small amount of nepheline (normatively amounting to 5%, *fide* Tröger, 1935, p. 229), between the plagioclase tabulae which were mantled by orthoclase, and he remarked on the transition toward gabbro which resulted from a decrease on the amount of nepheline (see Analysis No. 7, p. 179). Later, however, Lacroix (1927, pp. 10, 35–7) accepted and extended Smith and Chubb's (1927, pp. 318–322) modification of the definition of luscladite so as to include mesocratic medium to coarsely granular rocks with titanaugite, olivine and biotite as the chief dark constituents, plagioclase with or without potassic feldspar as an independent mineral, and nepheline (sometimes accompanied or replaced by sodalite), which may be as abundant as the coloured minerals and may enter into graphic intergrowth with the pyroxene. If the name be applied to all our rocks, its definition must be further extended to cover meso-leucocratic rocks in which nepheline is the dominant though not the sole sialic mineral, a complete departure from its original significance. We therefore follow Johannsen (1938, p. 197)

* See references cited by Morey and Ingerson (1937).

in his view that the term luscladite has become too vague to be useful, and believe that there is little to be gained by its adoption in place of the term olivine theralite which we have employed.

Comment may here be added concerning certain other rocks originally classed as nephelinites by Marshall (1912). The rock first noted by J. P. Smith on the beach at Omimi, fourteen miles north-east of Dunedin, has been found by the writer to be enclosed in a dyke of relatively fine-grained olivine nephelinite. The coarsely granular rocks form irregularly bunched segregations 1–3 feet wide, and may be drawn out into schlieren-streaks sometimes only 0·1–0·2 inches thick, passing by transitions into the surrounding nephelinite. The dyke probably fed a sheet of olivine nephelinite about 100 feet thick (possibly a sill rather than a flow), which extends for two miles under Porteous Hill, W.S.W. and W.N.W. of the exposure of the dyke on Omimi beach. Like the dyke, it varies in grain-size and texture, and also in its small content of feldspar, and encloses streaks of relatively coarse-grained material. We are not here dealing with independent hypabyssal coarsely-granular rock-masses as at Waihola, but with pegmatoid segregations such as Lacroix (1928) has described. Marshall's (1912, p. 306) clear account of the more coarsely granular rock together with his analysis thereof (No. 4) may be quoted, supplemented, and illustrated here. (See Fig. 3, 0.) "The olivine is" (often) "in extremely small needles, sometimes 1 cm. long but only 0·08 mm. wide. The direction of neighbouring crystals is remarkably parallel in longitudinal as well as transverse areas. They are similarly oriented over a considerable area." It is a strongly magnesian type, ranging in composition from Fa_{18}–Fa_{35} such as is normal in the atlantites. In some specimens the olivine has been more or less replaced by carbonates. "The phenocrysts of augite have the pleochroism and hour-glass structure as in the Waihola type." There is, however, usually little variation in the optic axial angle ($2V=(+)50°–58°$) which indicates a fully calcic character in all but one case of a zoned crystal with a thin mantle of less calcic composition with $2V=(+)36°$. "An appearance of lattice-structure in the feldspar (similar to that in the Waihola rocks) is very noticeable." The bulk of the feldspar in the coarsely granular segregations is anorthoclase with transverse optical plane and $2V=(-)52°–68°$, but andesine An_{45}–An_{39} is present as well. "The nepheline is wanting in crystallographic boundaries and is usually intergrown in complete micrographic fashion with augite. In some instances this augite is in optical continuity with the large crystals. This micrographic growth is sometimes formed in the ground-mass in a very minute scale and constitutes its dominant feature." (Fig. 3, 0, illustrates intergrowths of intermediate grain-size.) "The augite is sometimes slightly green in its smaller members. There are minute crystals of feldspar and apatite in the ground-mass. The larger crystals of apatite and ilmenite are the same as in the Waihola rocks." In slides of rocks other than those studied and kindly lent to the writer by Marshall, notably in 1048—a small pegmatoid segregation—there are occasional sub-radial clusters of rhönite showing its characteristic pleochroism (X=deep brown, Z=greenish brown), oblique extinction up to 10° in sections nearly perpendicular to (010), and up to 30° in sections

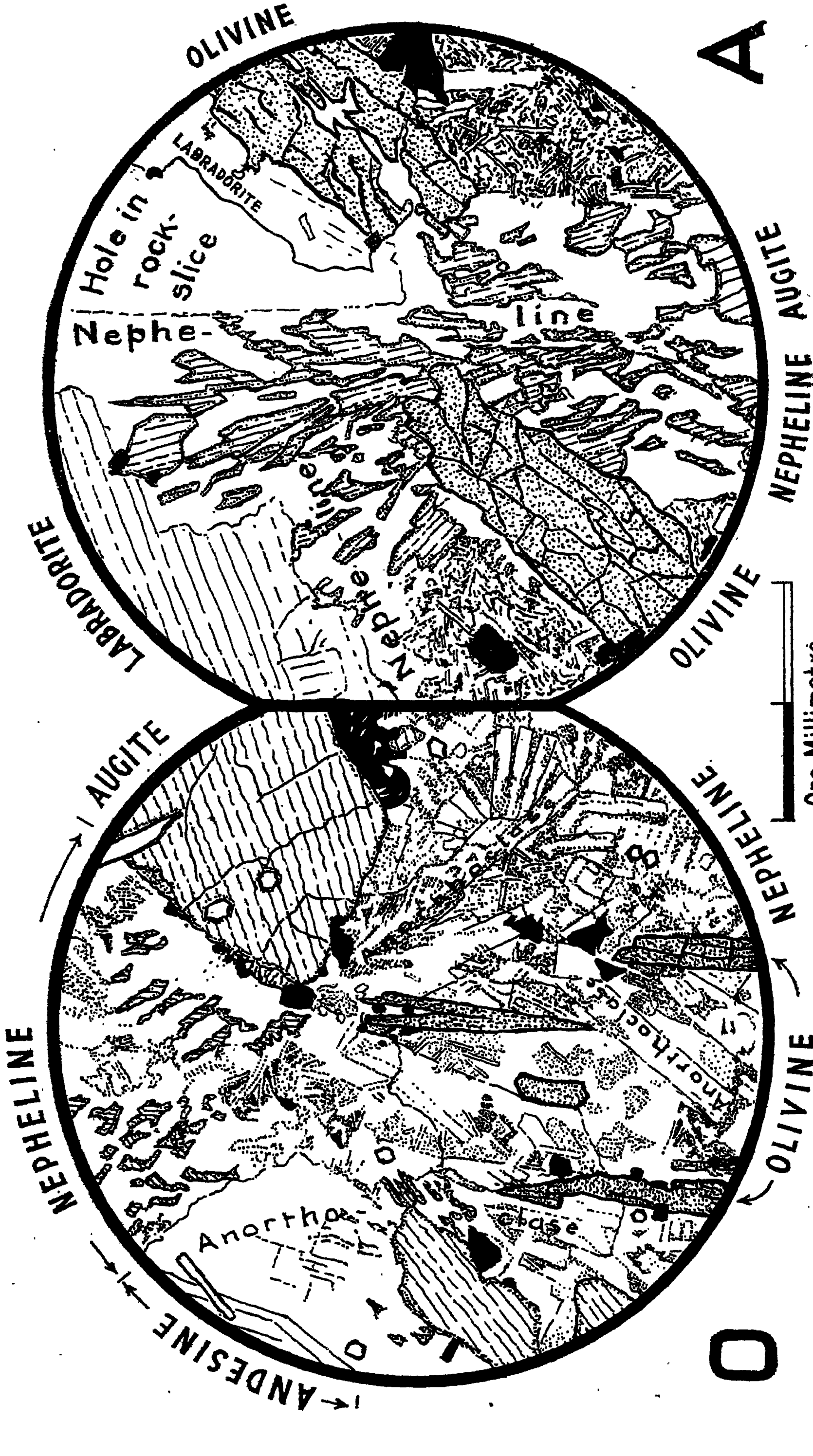

A
OLIVINE
LABRADORITE
Hole in rock-slice
Nephe-line
Nephe-line
AUGITE
NEPHELINE
OLIVINE
LABRADORITE
One Millimetre
O
AUGITE
NEPHELINE
Anorthoclase
Anortho-clase
OLIVINE
NEPHELINE
ANDESINE

FIG. 3

parallel thereto; refractive index about that of hornblende and birefringence near to 0·014. It is apparently a primary mineral in these rocks. In (1045), one of the more finely granular of these rocks differing but little from the enclosing nephelinite, a pegmatoid vein 4 mm. or more wide contains large grains of olivine (Fa_0–Fa_{18}) much more forsteritic than in the more coarsely granular rocks, and unzoned calcic titanaugite with large crystals of apatite and iron ores in a coarsely granular matrix of anorthoclase and nepheline, the latter in part graphically intergrown with pyroxene. A single small, almost rectangular plate of andesine (An_{45}) is all the plagioclase seen in this veinlet. Zeolitisation has occurred to greater or less extent in many of these segregations. The only (and possibly rather inadequate) analysis of these rocks that is available suggests that little or no feldspar was present in the specimen investigated.

The sheet of olivine nephelinite fed by this dyke, though doleritic in appearance (982, 983, 1069, 1082, 1100, 1121), is rarely as coarsely granular as the material of the large segregations in the Omimi dyke. It contains smaller idiomorphic crystals of titanaugite, partially bowlingitized olivine, occasionally (983) determinable as pure unzoned forsterite, magnetite and apatite set in a matrix of poikilitic nepheline more or less replaced by thomsonite (?) (and analcite ?), and of coarsely granular pericline-twinned plagioclase of composition An_{54-51} in one rock (983) in which it is associated with dominant anorthoclase, or An_{45-38} in another (1100) without any separate potassic feldspar.

The Domain Cricket Ground at Auckland, 650 miles to the N.N.E. from Dunedin, is situated in a crater in which large blocks of coarsely granular rock were found lying scattered on the land-surface, their mode of occurrence being indeterminable, though probably they formed segregations in the associated basaltoid lava in which Marshall stated (1907, p. 366, 1912, p. 307) a little nepheline occurred. This, however, has not been confirmed by Bartrum* after long search. The rock contains large crystals of olivine (Fa_{8-16} with narrow marginal zones of Fa_{24-30}), and is so richly pyroxenic that it (e.g. 7095) might be compared with ankaramite. Campbell Smith,* however, remarked in a letter (16, XII, 1929) to Professor Bartrum: "I should compare (this) with some of the limburgites with colourless glass in the interstices. There is very little feldspar present; I do not recognise any nepheline, but the glass would probably gelatinise with HCl, and if so might be taken for nepheline. Limburgites of this kind must be very nearly related to the basanites or nepheline-basalts." It seems probable that a chemical analysis of this rock would show the presence of normative nepheline as occurs in approximately coeval basaltic rocks in the district immediately south of Auckland. (Cf. Henderson, 1926.) If so, the term basanitoid, as redefined by Lacroix (1919) could be assigned to it. Marshall's description of the coarsely granular material (7085, 7091, 7101, 7107) may be illustrated by Fig. 3A and supplemented thus: It is somewhat similar to that of Omimi. In ~~most specimens the~~ augite in large grains has an ophitic form, but is less calcic than that of the Omimi rocks ($2V = (+) 42° \pm 3°$). It is strongly titaniferous

* Private communication. The writer is indebted to Professor Bartrum for details concerning these rocks and the loan of representative slides.

and shows hour-glass structure. The olivine crystals, again, have a great length, with elongation parallel to the *a* axis. The unzoned crystals in the most coarsely granular rocks have compositions between Fa_{37} and Fa_{49} and the zoned crystals Fa_{8-54}, while in a rock of medium grain-size an unzoned crystal of Fa_{61} and zoned crystals of Fa_{45-61} were noted. The intergrowth of augite and nepheline is very complete, but is not carried to the extent of excessive fineness that is found in the Omimi type. The ground-mass is rather more plentiful and contains aegirine, apatite and feldspar. The chief difference between the pegmatoid rocks of Omimi and those of Auckland lies in the dominance of feldspar in the latter, 53·2% of normative $Or_{29}Ab_{33}An_{38}$ being indicated in the rock analysed by Marshall (1912, No. 5 below), and 43% of normative $Or_{29}Ab_{25}An_{48}$ in that collected by Iddings and analysed by Washington (1917, p. 571, No. 6 below). Universal stage measurements indicating the modal character of the feldspars are recorded in Table II herewith.

It is not quite clear what is the most appropriate name for the coarsely granular rocks from Omimi and Auckland herein considered. As Marshall (1912) and Campbell Smith (*loc. cit. supra*) have noted, they have a general resemblance to the "nepheline dolerite" of Löbauer Berg in Saxony (Analyses No. 9 and 10)† which Rosenbusch (1908, vol. II, p. 1431) retained under the nephelinites. This rock, as shown by Stock (1888) and Siegert (1894), "forms schlieren in nepheline basalt of which the boundaries are not sharp, but denticulated and embayed" (Rosenbusch, 1907, p. 1432), as was clearly visible in the rock-exposures at that famous locality studied by the writer (Benson) in 1913. The New Zealand rocks, however, differ from those of Löbau, and also from the otherwise similar rocks of Fernando Noronha (Williams, 1889; Campbell Smith and Burri, 1933), also cited as analogues by Campbell Smith, in the fact that they contain abundant olivine and plagioclase. Campbell Smith therefore concludes (*loc. cit. supra*) "that the name nephelinite should not be applied to any of these coarse-grained 'nepheline dolerites.' They are not true lavas, but occur as small bodies, schlieren or inclusions and show many variations. There is a "close resemblance between the Auckland Cricket Ground boulders and the luscladite (Analysis No. 9) described by me (Smith and Chubb, 1927) from Rapa in the Austral Islands" (see below), "and I do not see any reason for not using that name unless it be that one ought to avoid using the name of a true intrusive rock for these small bodies and schlieren." Lacroix (1928) has called such bodies pegmatoids, and has used this word in conjunction with the petrographic names of volcanic rocks of corresponding mineral-composition. He (1928, p. 325) instanced the rock at Omimi as an example of ankaratrite pegmatoid. Johannsen (1938, p. 366) and apparently Tröger (1935, p. 255), following Lacroix's (1916, p. 256) original description of ankaratrites, have made the presence of 10–8 per cent. of biotite the chief feature separating them from more normal melanocratic

† For a detailed estimation of the (modal) mineral composition of this rock see Tscherwinsky (1929). The abundant apatite appears to be normal fluorapatite as analysis of a less melanocratic specimen than those recorded in Table II herein, (sp. gr. 2.888), gives P_2O_5 1.65%, $CaCl_2$ 0.04%, CaF_2 0.27%.

olivine nephelinites, the tannbuschite of Johannsen (1938, p. 364). But as Holmes (1920, p. 32) and (tacitly) Lacroix (1927, p. 22, 1928, p. 325) do not recognise this as an essential feature of ankaratrite, there seems little to be gained by the use of either Lacroix's or Johannsen's term in place of the longer but more descriptive name, which may be applied to a rock containing a very subordinate amount of feldspar. Johannsen's (1938, pp. 232, 301) term nephelinite-basanite may well be useful in denoting rocks in which the feldspar is not greatly subordinate to the nepheline, while in nepheline basanites plagioclase is in excess. On these grounds the coarse-grained rocks of Omimi are termed olivine nephelinite pegmatoid, those of Auckland nepheline basanite pegmatoid.

Brief mention may also be made of other rocks in New Zealand more or less closely related to those here discussed. Bartrum (1925, p. 10) has described a teschenite rich in analcite, and green-mantled titanaugite invading Cretaceous sediments at Mangapai on Whangarei Harbour about seventy miles north-north-west of Auckland.* Sollas and McKay (1906, 11, pp. 155–7) have described with very striking microphotographs several teschenites invading Lower Cretaceous strata, but possibly represented by tuffs and dykes in later Cretaceous beds, about sixty miles east of Wellington. They are being described in geological and petrographic detail by Brown and Hutton. In the Middle Waipara Valley in North Canterbury about thirty miles north of Christchurch, Dr. R. S. Allan and the writer found a number of pebbles of hitherto undescribed rocks of doleritic appearance which were probably derived from intrusions into Lower Mesozoic sediments, and though not exactly like the East Wellington rocks, may have been co-magmatic with them. They also are free from hornblende. The affinity is most marked in the case of 5777, an originally olivine-rich "natrolite"†-teschenite. The tabular (0·8 mm.) labradorite (An_{53}) is associated with a minor amount of orthoclase and is partly replaced by natrolite, though generally sharply idiomorphic against this locally abundant zeolite. Tyrrell's (1917) comment regarding analcite when paraphrased appears applicable to this rock. The zeolite was produced during "that late period in the history of the magma when the rock was stewing in a hot alkaline solution . . . Thus the (natrolite) was not derived from the feldspar but the alteration of the feldspar is due to the (natrolite)." Faintly tinted augite (0·7 mm.) is the dominant ferric mineral, but almost as abundant are chlorite-rimmed, slightly greenish-yellow bowlingite pseudomorphs after olivine, with accessory magnetite, ilmenite, apatite, and rare minute flakes of biotite. An otherwise closely-comparable rock (5778) differs from this in the presence of but little zeolite, mainly analcite. A more coarsely granular natrolite†-teschenite (5772) also containing but little zeolite, contains large flakes of biotite almost as abundant as the pyroxene and much of a scattered reddish-brown strongly birefringent chloritic mineral, which when aggregated is sometimes suggestive of iddingsite-pseudomorphs after olivine. There

* For analysis see Ferrar, 1934.

† This term is used in a general sense for radiating zeolite not clearly distinguishable from natrolite in a micro-slice. The precise nature of the Waipara zeolite has not been determined.

are also numerous porphyritic rocks with phenocrysts of two or all of the group labradorite (An_{55}), titanaugite and olivine, set in a medium-grained basaltic ground-mass in which accessory biotite flakes abound. Zeolitisation of the phenocrystic and ground-mass feldspar has occurred to a small but varying extent, and there are occasional zeolite-filled vesicles (Nos.: 5771–2, 5774–6). The pebbles of olivine-biotite-dolerite and olivine-dolerite found by Thomson (1913) in the bed of the River Dee are possibly co-magmatic with these. They were derived from the varied complex of dykes invading the pre-Cretaceous argillites of Mount Tapuaenuka, the highest point of the Kaikoura Ranges, about a hundred miles north-east of the Waipara River. Though they were considered of pre-Cretaceous age by McKay, Thomson suggests that they may be co-eval with the as yet undescribed basaltic flows in the Mid-Cretaceous sediments of the adjacent Awatere Valley.

Rocks from other Pacific lands more closely analogous to the Waihola, Omimi and Auckland theralites and basanites include the already mentioned luscladite of Rapa in the Austral Islands (Smith and Chubb, 1927, pp. 318–9. See Table 1, Analysis 11), which makes a plug 150 yards in diameter, and a number of other rocks occurring along the Main Dividing Range of Eastern Australia. Attention was first called by the writer (Benson, 1911) to the occurrence of nepheline-bearing basic igneous rocks at various points between 50 and 150 miles north of Sydney and later (1913) he noted their extension into south-eastern Queensland. Browne (1928, 1933) greatly increased the knowledge of these rocks and traced their extension into the south-eastern corner of New South Wales. Though the structural resemblance between some of these rocks and those of Löbauer Berg was noted, the presence of plagioclase caused the writer to term them olivine theralites or basanites. Some of them occur perhaps as basanite pegmatoids in more finely-grained lava (e.g. at Mount Warrawalong ?), but others form independent intrusive masses either as sills or plugs (*fide* Browne, 1933, pp. 63–67), associated with Tertiary olivine basalts, basanites and other more or less alkaline basic lavas. (See Table I, Analysis 12.)

TABLE I.—ANALYSES OF N.Z. THERALITES AND PEGMATOID BASANITES AND OF ROCKS ALLIED THERETO.

	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	36.00	40.50	43.14	45.30	46.00	46.66	45.01	44.46	39.88	39.43	41.56	41.86
Al_2O_3	14.51	14.89	17.77	16.44	16.79	18.57	14.35	13.14	15.37	10.36	11.16	14.40
Fe_2O_3	7.19	3.14	2.38	1.82	3.87	2.14	6.17	3.31	8.67	13.19	1.84	3.91
FeO	10.28	8.24	7.90	8.82	7.58	7.48	4.03	9.05	2.91	3.98	10.36	7.29
MgO	4.02	5.27	3.52	2.73	2.88	2.93	6.05	9.48	7.16	5.52	14.26	8.76
CaO	12.95	13.14	9.51	7.85	7.85	7.93	9.49	11.80	13.83	15.50	11.34	13.74
Na_2O	3.61	3.96	6.24	8.60	5.18	6.49	5.12	3.20	4.73	4.23	2.84	3.21
K_2O	3.04	2.04	2.10	4.05	3.31	2.79	3.69	1.45	2.01	2.24	1.49	0.91
H_2O-	4.40	2.95	2.89	2.96	3.04	0.70	2.60	0.84	2.17	0.81	1.01	2.23
H_2O+		0.90	0.88			0.20					0.29	0.79
CO_2	—	tr.	tr.	—	—	—	—	—	—	—	—	0.02
TiO_2	2.50	2.52	2.04	0.71	1.76	3.00	1.96	2.84	1.04	2.27	3.25	2.30
P_2O_5	1.56	2.24	1.22	1.68	1.76	0.40	0.74	0.48	2.29	2.76	0.49	0.67
ZrO_2	—	nt. fd.	nt. fd.	—	—	—	—	—	—	—	—	—
S	—	0.04	0.07	—	—	—	—	—	—	—	—	—
MnO	—	0.16	0.15	—	—	0.19	—	—	—	—	0.14	0.21
BaO	—	0.08	0.09	—	—	—	—	—	—	—	—	0.04
SrO	—	0.05	0.04	—	—	—	—	—	—	—	—	Abs.
Cr_2O_3	—	nt. fd.	nt. fd.	—	—	—	—	—	—	—	—	tr.
V_2O_3	—	0.05	0.03	—	—	—	—	—	—	—	—	0.01
NiO	—	0.01	tr.	—	—	—	—	—	—	—	—	tr.
Cl		tr.	tr.	—					—		—	tr.
F		0.15	0.10	—					—		—	—
Total	100.06	100.33†	100.07†	100.96	100.62	99.48	99.81	100.04	100.06	100.29	100.03	100.35
Sp. gr.	—	2.910	2.777	—	—	—	—	—	2.918	3.058	3.089	3.023

† Less O for F. 100.25 and 100.02 respectively. Fluorine estimated by Willard and Winter's method, slightly modified.

1. Coarse "Nephelinite" (Olivine Theralite). Lake Waihola. P. Marshall (1912) Anal.
2. Olivine Theralite (5067). Lower middle portion of Sill, Lake Waihola. F. T. Seelye Anal.
3. Olivine Theralite (5061). Upper portion of Sill, Lake Waihola. F. T. Seelye Anal.
4. "Nephelinite" (Olivine nephelinite pegmatoid with micrographic structure). Dyke, Omimi. P. Marshall (1912) Anal.
5. "Nephelinite" (Nepheline basanite pegmatoid). Isolated block, Auckland Domain. P. Marshall (1912) Anal.
6. "Nepheline Basanite" (Nepheline basanite pegmatoid). Auckland Domain. H. S. Washington (1917, p. 571) Anal.
7. Theralite. Average of six analyses. Daly (1933, p. 22).
8. Luscladite. Average of seven analysis. Lacroix (1920, p. 25).
9. Nepheline Dolerite. Löbauer Berg. Stock (1888) Anal.
10. Nepheline Dolerite. Löbauer Berg. Stock (1888) Anal.
11. "Luscladite" (Olivine Theralite). Rapa, Austral Islands. E. D. Mountain (in Smith and Chubb, 1927) Anal.
12. Nepheline Analcite Dolerite. Wharton's Mill, on road to Barrington Tops, New South Wales. W. G. Stone (in Browne, 1933, p. 69) Anal.

APPENDIX I.

Optical Measurements with the Universal Stage.

(F. J. Turner.)

Optical measurements were made with a Universal stage, for representative grains of feldspar, olivine, zeolite, and augite in typical thin sections. These determinations were used as a check upon the ordinary petrographic examination covering a greater range of material. The procedure for feldspars was the same as that described in a recent paper (Benson and Turner, 1940, pp. 194–196).

A note on the method of deducing the value of the true optic axial angle (2V) from universal stage measurements upon olivines (and augites), is appended in view of Tomkieff's recent discussion of this question (Tomkieff, 1939, pp. 234–236). The writer has followed Nikitin (1936, pp. 31, 32, pl. 1) in applying the correction for difference in refractive indices of olivine ($\beta = 1 \cdot 72 – 1 \cdot 78$) and the hemispheres of the stage ($\mu = 1 \cdot 648$), directly to all recorded tilts on E.W. or N.S. axes of the stage; at the same time crystals were selected in which tilting through low angles only was necessary, so that the corrections involved were always small. On the other hand, Tomkieff (*op. cit.*, p. 235) gives a table for conversion of apparent to true optic axial angle in olivine, taking into account (a) the magnitude of apparent axial angle and (b) the corresponding mean refractive index β for olivine of all compositions. However, the appropriate correction to be applied to measurements made upon grains of constant true axial angle is not constant, but depends upon the orientation of the grain in relation to the plane of section; if low tilts upon the universal stage are involved, the correction to be applied is less than in cases where higher tilts are necessary. An actual example of a zoned olivine measured by the writer in section 5067 is cited to illustrate this discrepancy.

Stage Readings.

	On inner circle.	On NS Axis.	On EW Axis.
Z parallel to EW	10½°	14°	
Y parallel to E.W.	279°	10°	
Optic axis vertical, with Y parallel to EW axis of stage — Inner zone			29°
Middle zone			24°
Outer zone			20°

From Nikitin (plate 1) the recorded tilts are corrected as follows:

Recorded.	Corrected.
10°	9¾°
14°	13½°
20°	18½°
24°	22½°
29°	27¼°

When the corrected tilts are plotted on a stereographic projection, the values of 2V obtained for the three zones (from within outward) are respectively 81½° (Fa_{34}), 72° (Fa_{54}) and 64° (Fa_{69}). On the other hand, if the procedure given by Tomkieff is followed, the corresponding corrected values for 2V are 82° (Fa_{35}), 70° (Fa_{58}) and 61½° (Fa_{74}) respectively. The discrepancy is noticeable only in cases where uniformly low tilts on the stage are recorded for olivines of high refractive index (i.e. rich in the fayalite molecule).

TABLE II.—UNIVERSAL STAGE MEASUREMENTS MADE BY DR. F. J. TURNER FOR THIS INVESTIGATION.

SLIDE.	OLIVINE.			PYROXENE.				FELDSPAR.	ZEOLITE
	Inner Zone. 2V	Outer Zone. 2V	Remarks.	Inner Zone. 2V	Outer Zone. 2V	$Z \wedge c$	Remarks.	Determination and remarks.	
5060 Waihola				54°–50° (+) strong $\rho<\nu$	44° (+) slight $\rho<\nu$		Outer zone purple, inner brownish with sharp intervening boundary.	1. Plagioclase An_{30} in tabulae 2 mm. square. 2. Anorthoclase microlites 2V= 48° (—) optic axial plane transverse to 010.	
5061 Waihola	—	—	—	—	—	—	—	1. Plagioclase An_{40} surrounded by Anorthoclase 2V=66° (—) with optic axial plane perpendicular to 010. The two feldspars show both pericline and albite twinning and are in parallel crystallographic position.	
5064 Waihola	76° (—) 80° (—) 82° (—)	72° (—) unzoned	No marked elongation	54° (+) 56° (+)	58° (+) 58° (+)		Purple, with outer zone very narrow.	1. Plagioclase An_{61}.	
5067 Waihola	81½° (—)	73½° (—) 65° (—)	All three measurements on 1 crystal. See Fig. 2	64° (+) *62° (+) 56° (+) 52° (+) 47° (+)	44° (+) 54° (+) 42° (+) 40° (+) —	— — — 40° 51° ±3° 52° ±3°	*Outer zone rather broad, with narrow greenish rim in which 2V=72° (+). Central zone sharply limited and all zones purple.	1. Anorthoclase laths 1.5 × 0.2 mm. 2V=45° (—). Optic axial plane perpendicular to (010). Partly replaced by zeolite. 2. Similar laths of plagioclase An_{65}.	Zeolite 2V=50°–60° (+) in several measurements elongated parallel to Z.
5068 Waihola	74° (—) 73° (—)	70° (—) 67° (—)	Very narrow outer zone	49° (+) 48° (+) 48° (+)	— 58° (+) 50° (+)	45° ±3° 53° ±3° 40° 43° 48°	Purplish core with very pale outer zone.	1. Anorthoclase in tabulae—less than 2×1 mm. 2V=45° (—). Optic axial plane often transverse to (010). 2. Small laths of probably similar composition.	
5098 Waihola	73° (—)		Not appreciably zoned. Partial alteration to iddingsite	48° (+) 62° (+) 63° (+)	50° (+)		Inner zone deep purple. Outer pale purple followed by greenish mantle with 2V=58° (+). } Purplish } unzoned.	1. Plagioclase An_{30} in tabulae 2×2 mm. 2. Anorthoclase microlites with 2V=48° (—) and optic axial plane transverse to (010).	Zeolite, elongated parallel to Z. D.R. = 0.010 approx. Slightly greater than that of feldspar. 2V=60° ±5° (+) in several measurements. 30° (+) in one only (Thomsonite).
5699 Waihola	81° (—)	70° (—)	Ophitic with very narrow outer zone	54° (+)	40° (+)	45° ±3°	Crystals ophitic with very sharply distinct zones.	Plagioclase tabulae with Carlsbad, albite, and sometimes pericline twinning. 1. In olivine (a) An_{67} (b) An_{80} (c) An_{60} with narrow outer zone of An_{75}. 2. In augite (a) An_{53} (b) An_{70}. 3. Free zoned tabulae, centre	

								An_{58}, narrow border An_{45}. 4. Free unzoned laths rare An_{44}.	
5700 Waihola	88° (—) 80° (—)	80° (—) 74° (—)	Nearly perpendicular to optic axis. Variation of extinction between inner and outer portion. See Fig. 2						
983 Porteous Hill (Sill?)	88° (+)		Unzoned					1. Anorthoclase dominant. Carlsbad and pericline twinning. 2V = 52°–68° (—). Axial plane transverse to (010). 2. Plagioclase An_{54-61}.	
1045 Omimi dyke. (a) Main mass	88° (—) 81° (—)	82° (—)	Narrow outer zone. Unzoned	58° (+) 54° (+) 50° (+) 50° (+) —	36° (+) —	40° 40°	Unzoned. Good determination of $Z \wedge c$.	1. Anorthoclase dominant with 2V = 66° (—). 2. Plagioclase subordinate An_{45-50}.	
(b) Narrow pegmatoid veinlet	86° (+)	88° (—)	Large grains	—	—	—		Almost wholly anorthoclase with 2V = 55° (—) to 70° (—). One crystal has a small inclusion of plagioclase An_{55}.	
1100 Porteous Hill								1. Plagioclase An_{45-55}. No anorthoclase determinable.	
7085 Auckland Domain Nepheline basanite pegmatoid	80° (—)		DR. = 0.041 assuming DR. of Ab_{98} = 0.008	42° ± 3° (+)			Not markedly zoned.	1. Plagioclase An_{45-54} unzoned. abundant and coarsely granular. 2. One small crystal of An_{54} surrounded by pericline-twinned anorthoclase 2V = 62° (—), followed by incomplete mantle of K feldspar with 2V = 40° (—). 3. Anorthoclase (or sanidine) microlites.	
48F Auckland Domain Coarse basanite pegmatoid	86° (—) 74° (—)	80° (—) 72° (—)	Narrow outer zone. Unzoned crystals elongated ‖ to *a*.					SLIDES IN COLLECTION OF GEOLOGICAL DEPARTMENT, AUCKLAND UNIVERSITY COLLEGE.	
Medium-grained basanite pegmatoid	72° (—) 76° (—) 68° (—)	68° (—) 72° (—)	Crystals elongated ‖ to *a*. Square cross-section ⊥ to *a*.						
22 Fine-grained basanitoid? adjacent to coarse-grained rock	89° (—) 88° (+) 88° (+)	83° (—) 86° (—) 86° (—)	Very large grains with narrow outer zones.						

APPENDIX II.

DESCRIPTIONS OF ZEOLITE, TITANAUGITE AND APATITE IN AN OLIVINE THERALITE AT LAKE WAIHOLA.

BY C. O. HUTTON.

The zeolite separated from theralite 5698 described above is apparently homogeneous. The specific gravity at 19° C. is 2·25–2·26, and the refractive indices repeatedly determined using a variety of oils to avoid any effects of base exchange, give consistently the values α=1·5073, β=1·5095, γ=1·5160 (each ±0·0003) with γ–α 0·0087. These show that the mineral is not natrolite, but is more nearly allied to the thomsonite group. The optic plane and acute positive bisectrix are parallel to the length of the fibre in nearly all cases in material mounted in Canada balsam. Rarely, however, the fibres are twinned, one segment being positively elongated, the other negatively. This also holds true when the mineral has been mounted in oil, after being warmed on the hot plate just sufficiently to permit mounting in Canada balsam. But if the mineral be mounted in oil without this brief heating, nearly all the fibres are negatively elongated, and but few positively. The same is true of the heated mineral which has been subsequently cooled and mounted in a drop of water. It would seem as if the heating brought about sufficient dehydration to change the optical properties significantly, but the original condition is regained when water is returned into the crystalline mesh. The optical orientation makes it difficult to measure accurately the value of 2V. That calculated from the above refractive indices is about 50°(+), that measured by Dr. Turner on the heated mineral mounted in balsam is generally nearer 60°±5°(+) but rarely 30°(+). The composition of the zeolite as determined by Mr. F. T. Seelye is peculiar in its content of K_2O, which is abnormally high for a member of the thomsonite group of zeolites.

TABLE III—ANALYSIS OF ZEOLITE.

	Waihola Zeolite.	Mol. Prop.	Atomic ratio 80 atoms of O in unit cell.	Hey's Thomsonite No. 1.
SiO_2	42.10	0.701	22.91	40.3
Al_2O_3	26.87	0.263	17.19	28.5
Fe_2O_3	0.21			
FeO	0.36			
MgO	0.35			
CaO	5.16	0.092	3.00	11.2
Na_2O	8.50	0.137	8.95	5.7
K_2O	2.63	0.028	1.83	nil
H_2O+	11.35	0.773	25.26	14.1*
H_2O-	2.57			
CO_2	nt. fd.			
TiO_2	0.03			
P_2O_5	0.01			
MnO	0.03			
BaO	nt. fd.			
SrO	0.04			
Cl	nt. fd.			
	100.21			99.9

* Assuming Hey is using total Water.

After considerable search it has not been possible to find an analysis completely comparable with that of the Waihola zeolite. The nearest approach is one listed by Hey (1932, p. 54, table 1) which is given above. It would appear from this that the Waihola zeolite is a potash-bearing member of the thomsonite group near its extreme end containing thomsonite rich in SiO_2 and poor in Al_2O_3. The refractive indices of the Waihola material are also in accord with the generally decreasing value of the indices towards this end of the group. Further, its analysis, recalculated on the basis of 80 atoms of oxygen per unit cell, would tend to confirm its position in that group, though K_2O is more abundant in it than in any thomsonite described by Hey. Its formula would appear to be $Ca_3Na_{8.95}K_{1.83}Al_{17.19}Si_{22.91}O_{80}$ 25·26 H_2O with Al+Si=40·10 and Ca+Na+K=13·78. These figures agree fairly well with Hey's data, and the latter would seem to show that the $Na \rightleftharpoons K \rightleftharpoons Ca$ substitution is of importance.

No name is suggested here for this zeolite. Certainly Hey's (1933) work on ashcroftine leaves the term kalithomsonite available, but it seems undesirable to revive it by its application to the Waihola zeolite.

The titanaugite (separated from the thin greenish mantle enriched in aegirine-augite) has the following properties:—Sp. gr. at 16° C. = 3.425±0·005. Refractive indices $\alpha = 1{\cdot}698$, $\beta = 1{\cdot}704$, $\gamma = 1{\cdot}724$ (each ±0·001) and $\gamma - \alpha = 0{\cdot}026$. The value of 2V calculated from these figures is about 60° (+), that measured by Dr. Turner on the purplish augites in this rock varies from 48° (+) to 63° (+). In the absence of twinning it was not possible to measure the angle $Z \wedge c$. The composition according to Seelye's analysis is as follows:—

TABLE IV—ANALYSIS OF AUGITE.

	Waihola T. augite.	Waihola Mol. Prop.	Atomic Ratio to 6 (0.0H).			(1)	(11)
SiO_2	45.28	0.754	1.724		2.00	45.56	44.71
Al_2O_3	7.60	0.075	0.343	0.276 0.067		8.15	7.85
Fe_2O_3	2.45	0.036	0.068			2.46	4.40
FeO	7.48	0.104	0.238			5.46	4.23
MgO	10.31	0.257	0.587			11.88	11.74
CaO	22.45	0.401	0.917			22.84	22.37
Na_2O	0.60	0.010	0.023			1.02	0.90
K_2O	0.07	—	—			0.62	0.09
H_2O+	0.26	—	—			—	0.26
H_2O-	0.12	—	—		1.98	—	0.09
CO_2	nt. fd.	—	—			—	—
TiO_2	2.88	0.036	0.082			1.87	2.92
P_2O_5	0.40	—	—		—	—	0.12
V_2O_3	0.047	—	—		—	—	—
S	0.02	—	—		—	—	—
MnO	0.18	0.002	0.004			0.42	0.10
NiO	tr.						
BaO	nt. fd.					—	—
SrO	$<$ 0.01						
Cl	nt. fd.						
	100.16					100.28	99.84*

* *Min. Abstracts*, vol. 24, p. 212, gives 100.34.

Analysis (I) by A. Hueber (in L. Jugovics. Constitution of the Basalt Plateau of Mount Medves and its Crystal Tuff. *Mat. Természettud, Ertesitó,* Budapest. 1934. Vol. 51, pp. 443–470) is of an augite with sp. gr.=3·31, 2V=57°23′, and $Z \wedge c$=45°2′ to 47°5′. A better comparison with the Waihola titanaugite is, however, afforded by (II) a titanaugite from a monzonitic teschenite (W. Wawryk. Sur l'augite commune et titanifère des teschénites en Pologne, *Arch. Min. Tow.* Nauk. Warszaw. 1935. Vol II, pp. 175–181). On this augite 2V=51°. $Z \wedge c$=50°, and α=1·721, β=1·725, γ=1·746; sp. gr.=3·401. The main difference between this and the Waihola titanaugite lies in the higher ratio of Fe_2O_3 to FeO, though the total iron content remains about the same. It is significant that the higher oxidation of the iron in (II) appears to have caused considerable increase in the refractive indices. The presence of P_2O_5 in the Waihola augite is attributed to the occurrence of fine needles of apatite within the pyroxene grains, and not to the presence of apatite grains associated externally with the purified (centrifuged) powder. Allowance has been made for the lime associated with the P_2O_5 in calculating the formula for this augite. On the basis of 6 (O.OH) atoms to the unit cell, the analysis agrees well with the structural formula $XY\ (SiAl)_2(O,OH,F)_6$ suggested by Machatschki (1929) yielding, as shown above, the formula $(Mg, Fe'', Fe''', Al, Ti, Ca, Mn, Na)_{1.98}\ [(Si, Al_2)O_6]$. Here the Al is split between the Si and XY groups to satisfy the silicon chains of the pyroxene structure. Although the augite is fairly titaniferous, none of the Si is replaced by it, as apparently can take place in augites high in Ti but low in Al. If the Fe_2O_3 be calculated as 2FeO and the Al_2O_3 and TiO_2 be ignored, there is not quite sufficient silica to give the formula $Wo_{48}En_{36}Fs_{22}$ which would correspond with positions on Deer and Wager's (1938) triangular diagrams which otherwise accord fairly well with the optical properties observed.

Apatite separated from the same rock has sp. gr.=3·16±0·01 and ω=1·6370 and ϵ=1·6339, both ±0·0002. These figures are within the ranges given by Hausen (1929) for the normal apatites. The composition calculated from Seelye's analyses of the Waihola theralites is that of a nearly pure fluor-apatite.

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CORRIGENDA.

Dr. C. O. Hutton has kindly indicated that certain rocks in the collections of the New Zealand Geological Survey and described by the writer in Basic Igneous Rocks of Eastern Otago and their Tectonic Environment, Part II, *Trans. Roy. Soc. N.Z.*, vol. 72, pp. 85–110, were not cited by numbers corresponding with those they bear in the Survey's official catalogue. The following corrections should be made:—

Page 92—Locality 4.	For P.5561	read	P.4129.
Page 93—Locality 9.	For P.5167	read	P.4167.
Locality 19.	For P.5597	read	P.5594.
Page 94—Locality 23.	For P.5598	read	P.5595.
Locality 24.	For P.5576	read	P.5570.
Locality 25.	For P.5577	read	P.5574.
Locality 26.	For P.5584	read	P.5578.

The Breeding Habits of *Cryptoconchus porosus* (Burrow)

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[*Read before the Otago Branch, November 11, 1942; received by the Editor, April 4, 1942; issued separately, September, 1942.*]

Up till now no detailed description has been given of the breeding habits of Chitons, though several interesting points in reproduction have been described by Metcalf [11], and spawning is briefly alluded to by Clark [2], Hammarsten and Runnström [8], Heath [9], and Lovén [10]. Careful observations of the habits of Chitons have been made by Crozier [3], [4], [5] and Arey in conjunction with Crozier [1], but the only reference that I have found to *Cryptoconchus porosus* is in a paper recently published by Graham [7]. Unfortunately, the date and time of spawning recorded by him do not agree with my observations, nor have I ever seen egg capsules such as he describes.

During the years 1938, 1939, and 1940 observations were made of the breeding habits of *Cryptoconchus porosus,* a fairly large Chiton which occurs throughout New Zealand and the Chatham Islands (Suter [13], Powell [12]). Adult specimens are found on the sides and under-surfaces of rocks just below low-water mark in sheltered situations, where plant and animal life is particularly abundant. They are usually found singly. Very rarely two or three occur on the same rock and they are never found in clumps.

Each year specimens were collected towards the end of April and placed in an aquarium, where conditions were kept as like those of the natural habitat as possible. Periodically excursions were made to the collecting grounds in order to keep a check on laboratory observations. It was found that dates and times of spawning of those in the natural habitat coincided with those in the laboratory.

Laboratory records are given in Table I which records the length and sex of the individuals under observation, the date, time, and duration of spawning and the phase of the moon. Perusal of this recording shows:—

(1) Spawning occurs five times over a period of 2–2½ months in the winter.

(2) The first three spawning periods are the most important, and, during them, all sexually mature individuals produce eggs or sperms. During the last two periods there is a marked decrease in the number of spawning individuals. (Note: After the third period in 1938, the aerating apparatus failed and all specimens died shortly afterwards.)

(3) Though occasional males produced sperms earlier in the year (1939, 1940), the breeding season proper commenced late in June or early in July and always at the time of full moon.

(4) The time elapsing between two spawning periods is, on the average, 15 days—the time which elapses between full and new moon.

(5) On some occasions eggs were produced first, on others sperms.

(6) In normal years (1938, 1940) spawning took place during four or five days about full or new moon.

(7) With few exceptions eggs and sperms began to be extruded between 10 a.m. and 12 noon, and the time of discharge was two or more hours.

(8) Of the twenty-two specimens under observation thirteen were females and nine males, and over 75% of the larger specimens were females.

(9) The only specimen which did not prove mature was the smallest, 55 mm. in length. The next smallest, a 63 mm. male (1939), did produce sperms.

OTHER RELEVANT OBSERVATIONS.

(a) *Activity preceding Spawning.*

Normally *C. porosus* displays very little movement during the day, the animals tending to remain attached to the rocks or to the floor of the aquarium. One or two days before spawning, however, they exhibit a marked tendency to rise to a position just beneath the water level, and circumnavigate the tank (or rock) until spawning itself commences. Metcalf [11] has recorded this phenomenon in *Chiton squamosus.*

(b) *Discharge of Genital Products.*

The respiratory current conveys genital products to the exterior. They emerge through openings on the inner side of the pallial groove between the 4th and 5th gill from the posterior end.

Previous to the actual extrusion of eggs and sperms the animal takes up a characteristic position on the side of the tank or just under an outjutting ledge of rock. The head is directed downwards, the anterior region of foot and mantle pressed tightly to the substratum, the posterior region elevated to an angle of about 60°, and the mantle edges rolled inwards, in the region of the genital apertures, to cover over the pallial groove. This position is illustrated by the female in the centre of Plate 13, Fig. 1, and by the female in Plate 13, Fig. 2. The elevation of the posterior region may well be to ensure that genital products fall at some distance from the parent as shown by sperms produced by the male at the left of Plate 13, Fig. 1. The male in Plate 13, Fig. 2, illustrates a position less frequently assumed, the individual remaining on the floor of the tank or on the bottom of the sea.

(c) *Genital Products.*

Large quantities of minute white sperms are produced, one male alone being able to render an eight litre tank completely cloudy and giving it a peculiar pungent odour. Sperms under laboratory conditions remained active for 2–3 days.

Eggs are also produced in great numbers. Long gelatinous strings emerge from the genital apertures. These strings are not broken by gentle wave action, but become greatly extended. The eggs are from 0·4–0·6 mm. in diameter, olive-green in colour, or greenish-yellow. Each is protected by large cup-shaped follicle cells. Fertilised eggs show the first cleavage furrow three hours after fertilisation. (Note: The olive-green eggs gave a higher percentage fertility.) If not fertilised, eggs began to disintegrate after 24 hours.

(d) *Sex Colouration.*

This has previously been recorded for *Chiton tuberculatus* by Arey and Crozier [1], who state: "At sexual maturity the female *Chiton tuberculatus* is coloured in a different way from the male;

its tissues are impregnated with a salmon-pink substance concerned in the metabolism of the ovary. If the shell plates are separated this differential coloration of the sexes may be detected in dorsal view. Normally it is quite invisible.''

In *Cryptoconchus porosus,* the shells are almost completely covered by the fleshy mantle, but the two sexes can be differentiated readily by the colouring of the mantle itself. In both sexes the basic colour is olive-green. In the female this colour is obscured by splashes of dark brown, whilst in the male it is broken by patches of brilliant orange. This orange pigment also occurs in the wall of the testis. Thus in contrast to *Chiton tuberculatus,* the orange colouring in this species is characteristic of the male.

Discussion.

The regularity with which spawning periods coincide with the appearance of full and new moon is so marked in the years 1938 and 1940 that it would appear necessary to find some reason to account for it and for the irregularity in the year 1939.

In the first place, however, the question of what induces spawning must be discussed. Individuals of *Cryptoconchus porosus* show no tendency to accumulate in groups before or during spawning, nor do isolated individuals of either sex fail to produce sperms or eggs at the same time as the others. Added to that, Table I shows that the presence of sperms is not necessary to stimulate the female or *vice versa.* From these facts it would appear that either the internal metabolic rate itself is responsible for the regular intervals between spawning, or some purely external factor is responsible.

The length of time needed for the ripening of the sex cells in the gonads will depend entirely on the metabolic rate of the animal and should be approximately the same for animals living under the same conditions. Under normal conditions the length of time needed for the ripening of the eggs and sperms should remain fairly constant as it did in 1938 and 1940, and thus a periodicity would arise—ripening of gonads—spawning—ripening of gonads—spawning, etc. Unfavourable conditions, however, would upset this rhythm, but if conditions became normal again the rhythm should be restored. This seems to be the case in 1939, when the 2nd spawning was delayed by 4 days, the 3rd by 6, the 4th by 7 and the 5th by 7. Table II gives a comparison of the average 9 a.m. temperatures recorded at Dunedin for the Meteorological Department between new and full moon for the years 1939 and 1940.

Table II.

Average Air Temperatures.	1939.	1940.
Av. Temp. for 15 days before 1st spawning	46.8° F.	44.7° F.
Av. Temp. between 1st and 2nd spawnings	*39.5° F.	42.8° F.
Av. Temp. between 2nd and 3rd spawnings	†34.6° F.	40.9° F.
Av. Temp. between 3rd and 4th spawnings	*39.9° F.	43.1° F.
Av. Temp. between 4th and 5th spawnings	41.7° F.	45.3° F.

Average Temperature for the period before each Spawning in 1939 and 1940.

* Represents a heavy snowfall.

† An extremely heavy snowfall.

The snow, which fell before the second spawning period, was probably responsible for delaying it. This delay was accentuated by the extremely heavy snowfall before the third period, and still further by the lighter fall before the 4th. Then improvement in conditions restored the usual time for ripening of the gonads and normal rhythm was resumed. Arey and Crozier [1] found, in their experiments in the Bermudas, in *Chiton tuberculatus* normally adapted to a temperature of 26°–27° C., that below 15° C. an anaesthetised condition was arrived at. *Cryptoconchus porosus* is adapted to a temperature of 15° C. so that the temperature below which it would become anaesthetised would be much lower. During the very cold periods of 1939, specimens kept in a comparatively shallow aquarium would naturally be subjected to falling temperatures and along the shore the melting snow would lower the temperature of the water slightly.

Although the internal metabolic rate may account for periodicity in spawning, it will not account for the fact that each year spawning started at full moon. The coincidence of full moon and spawning has been noted for many marine animals, but no thoroughly satisfactory reason for it has been propounded. Fox [6] suggests that bilunar periodicity may be due to polarised light. As the polarisation of the light of the moon is greatest at the first and third quarters, it seems unlikely that seven days would elapse between the stimulus of poralised light and the actual spawning. Fox's other suggestion [6], that the moon may perhaps cause a lunar cycle in reproduction by the additional total number of hours of illumination per 24 hours at full moon over and above a threshold light value, may account for the coincidence of full moon and the first appearance of eggs and sperms, in that spawning commences in the middle of the winter, when the number of hours of daylight is at a minimum. Under these conditions the extra number of hours of illumination would be a sufficient stimulus to initiate spawning.

The full tides which accompany full and new moon are probably useful in that the greater ebb and flow at these times helps to distribute eggs and sperms and thus ensure a greater percentage of fertilisation. Two objections can be raised to tidal rhythm as a causal factor in the spawning of *Cryptoconchus porosus*. One objection is that no matter at what time of the day the tide is full, spawning begins with great regularity between 10 a.m. and 12 noon. The increased illumination is probably the cause of the regularity of the actual spawning time, although no retardation occurred on dull days. On three of the four occasions on which spawning commenced in the afternoon, other individuals on the same day spawned at the normal time, indicating that delay was not due to external factors of temperature, light intensity, etc., but to the condition of the actual individual. The other objection is that, unlike *Chiton tuberculatus* which lives on rocks left exposed at low tides and which spawns upon submergence by the rising tide (Arey and Crozier [1]), *Cryptoconchus porosus* lives beneath the low-water mark, and is therefore less influenced by the rising tide. A theory which would account for a tidal rhythm, however, is that the ancestral chitons became adapted to life near the high-tide mark, where spawning was only possible at times of spring tide. A tidal rhythm was thus imposed and has not been lost by species like *Cryptoconchus porosus* which may be supposed to have taken secondarily to a submerged life.

From the above statements the following summary may be made to account for the rhythmical periodicity of spawning. The original stimulus is the increased number of hours of illumination per 24 hours at the time of full moon, and the rhythmic sequence of breeding periods is due to the internal metabolic rate of the individual. Under normal conditions the breeding periods coincide with new and full moon and the accompanying spring tides, but under the effect of low temperatures the metabolic rhythm is upset and the coincidence of spawning with the phase of the moon is also upset. A tidal rhythm may have been acquired from ancestral types which lived higher up the shore, where spawning was possible only at spring tides. The regularity with which individuals start to deposit eggs or sperms at a certain time of the day may be due to the increased illumination during daylight.

Summary.

Over a period of three years, 22 specimens were kept under observation for approximately six months.

An extremely marked bi-lunar periodicity in spawning is recorded, there being five breeding periods, throughout 2–2½ months in the winter.

Phenomena associated with spawning are described and the different colouring of the mantle in the two sexes noted.

An attempt is made to account for the remarkable rhythm of spawning and the regularity with which it commences between 10 a.m. and 12 noon.

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FIG. 1

Three specimens of *Cryptoconchus porosus* photographed in the aquarium. The male on the left is clinging to the side of the tank just below the water level. A string of white sperms is pouring from the exhalant respiratory aperture at the posterior end. The general whiteness of the floor of the tank is due to the presence of sperms. Both the other individuals are females, the one on the right resting after spawning, whilst the central one is in the act of extruding eggs, which can be seen as a grey mass on the floor of the tank between the two females.

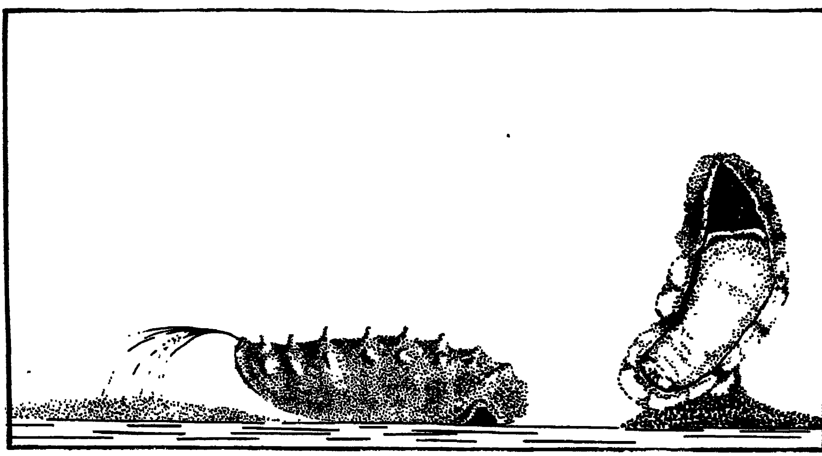

FIG. 2

Drawings of a male (left) and a female (right) made from photographic negatives. The male is shown spawning on the floor of the tank, and the force by which sperms exit by the exhalant respiratory aperture at the posterior end is illustrated. Note the inhalant respiratory aperture at the anterior end. The female shows the usual position for spawning, head directed downwards, posterior region of foot and mantle elevated, mantle edges rolled in over pallial groove in this region. The eggs are shown pouring out of the exhalant respiratory aperture passing down the back of the animal in a long gelatinous string, and forming a pile on the floor of the tank.

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Vol. 72, Part 3.

GEOLOGY.

LIST OF PLATES

Francolite, a Carbonate-Apatite from Milburn, Otago.

By C. O. HUTTON and F. T. SEELYE.

[*Read before the Wellington Branch, Royal Society, August 13, 1942; received by Editor, August 19, 1942; issued separately, December, 1942.*]

INTRODUCTION.

FRANCOLITE, a carbonate-apatite, with the formula $(Ca,C,Na,K)_{10}$ $(P,Si,C,Al)_6$ $(OH,F)_{3.3}$ $O_{22.7}$ has been recognized in a quartz-sandy type of phosphorite from near Milburn, Table Hill Survey District, Otago Land District. The phosphorite has been described by Ongley (1939, p. 83) as sandstone, but its true nature has more recently been pointed out by Macpherson (MS.).

The mineral has been separated from the phosphorite in the pure state, analysed and optical and chemical properties determined. These facts are compared with similar data obtained from literature available to the writers. Finally, the petrography of the francolite-bearing rock is given and attention is drawn to its similarity with the Russian phosphorites of the Briansko-Kurski area.

PHYSICAL PROPERTIES.

The phosphate mineral occurs in stumpy hexagonal, or pseudo-hexagonal prisms, usually terminated at one extremity only by basal plane and low pyramids. The crystals rarely exceed 0·6 mm. in length. They are colourless, but show clouds of minute dust-like inclusions of haematite or limonite. The inclusions are commonly regularly arranged so that a central hexagonal zone is heavily charged, leaving the periphery quite clear. The refractive index of the central portion appears to be very slightly less than that of the peripheral zone, although no other differences in optical properties were noticeable.

In a hexagonal section, γ of the refractive index ellipsoid is observed to be parallel with the hexagonal edge in each triangular sector of the twinned crystal, and not at an angle to it as found by Deans (1938, p. 136). Thus the Milburn francolite appears to be similar to that described by Lacroix (1910, p. 558) from the Vosges, and by Sandell, Hey and McConnell (1939, p. 397) from the mine Wheal Franco, Tavistock, Devon. In other cases basal sections do not show any evidence of repeated twinning and, therefore, are isotropic or extinguish uniformly. The refractive indices are closely comparable with previous data, some of which are given in Table I.

TABLE I.

Optical Properties of Francolite.

	α	β	γ	$\gamma-\alpha$	Reference.
1.	1.620	1.627	1.628	0.008	Deans, 1938.
2.	1.624	—	1.629	0.005	Sandell, Hey and McConnell. 1939
3.	1.619	—	1.628	0.009	McConnell, 1938B.
4.	1.614–1.617	1.627	1.627–1.630	0.013	de Villiers, 1942.
5.	1.620–1.622	1.624–1.627	1.625–1.627	0.005	This work.

The mineral is negative with an optic axial angle ranging from 0°–25° (±2°). Measurement of the angle on the universal stage

was a matter of some difficulty because of the fine grain-size and low birefringence. However, it was clearly seen that the optic axial angle varied from grain to grain, and sometimes within individual grains. The acute bisectrix is normal to the basal plane, hence prismatic crystals have negative elongation.

Chemical Properties.

The characteristic feature of francolite or the carbonate-apatites in general as compared with normal apatites, is that the carbonate-apatites are soluble in warm dilute hydrochloric acid with liberation of bubbles of CO_2.

In order to prepare a pure sample of francolite for analysis, the phosphorite was first crushed carefully and the larger quartz grains were screened out. The concentrated material was then ground to pass through a 200-mesh screen and the product elutriated carefully to rid the product of some of the clay fraction. Finally, the concentrate was centrifuged in bromoform-methylene iodide mixtures. The authors consider that a pure product was obtained, except that it was not possible to free the fine francolite particles entirely from minute inclusions of iron-ore. Close inspection of the purified product did not reveal any grains of quartz. In Table 2, the analysis of the Milburn francolite is compared with other data obtained from the literature, and it will be noted that a very close correspondence exists between these analyses and that of the Milburn mineral. The classification of the mineral as francolite rather than dahllite is based on McConnell's (1938A, p. 9) suggestion that dahllite should be limited to those types containing less than one per cent. of fluorine while francolite has more than this amount. The specific gravity, as determined with centrifuged material is 3·15–3·18. These figures may be a trifle high on account of the presence of tiny inclusions of iron-ore in the francolite.

Gruner and McConnell (1937) have shown that the structure of francolite is essentially similar to that determined by Náray-Szabó (1930) and Mehmel (1930, 1931) for fluor-apatite; and, further, Gruner and McConnell (1937) have demonstrated that the CO_2 present could be accounted for in terms of the structure of apatite. Therefore, the analysis of francolite from Milburn has been recalculated (Table 3) on this basis, after excluding Fe_2O_3 and FeO; that is, asssuming 42 atoms to the molecule, and with (O,OH,F) equal to 26. The main group, Ca, P and C, has been calculated to a total of 16 atoms to the unit cell, with F and OH calculated in the same ratio.

In this analysis (Table 3) we find additional evidence of the types of substitution shown to occur in ellestadite (McConnell 1937, p. 977), francolite (Gruner and McConnell 1937) and dahllite (McConnell 1938B). Silicon and aluminium, together with 0·353 atoms of carbon, the latter forming CO_4-groups with a tetrahedral configuration, are assigned to phosphorus positions in order to make up the group to the theoretical figure of six. Sodium and potassium, together with the remainder of the carbon ions enter the lattice in the calcium positions. Although Si-ions enter the lattice in the phosphorus positions, S-ions, which might be expected, are not present. The amount of substitution by carbon in the calcium and

phosphorus positions, viz. 0·395 and 0·353 atoms per unit cell, appears to bear out the fact that as carbon goes into the calcium positions the birefringence of the mineral becomes lower. The scanty data available suggest that in a francolite in which calcium only is replaced by carbon, the birefringence may be reduced to a negligible figure. However, as de Villiers (1942, p. 446) points out, information on this is not yet available.

TABLE 2.

Analyses of Francolite.

	A.	B.	C.	D.	E.	F.
CaO	51.30	51.02	54.88	54.64	53.94	54.84
SrO	—	—	—	0.13	—	—
MnO	tr.	—	—	nil	—	—
MgO	0.41	0.47	0.31	tr.	0.10	0.53
Na_2O	0.46	0.71	—	nil	—	0.20
K_2O	0.17	0.57	—	nil	—	—
CO_2	3.20	5.79	3.36	1.98	3.40	4.43
P_2O_5	34.63	33.01	37.71	38.25	38.13	35.01
SiO_2	2.27	tr.	—	nil	—	—
SO_3	nil	1.77	nil	nil	nil	—
Al_2O_3	1.18	0.20	—	} tr.	—	—
Fe_2O_3	2.11	0.66	—		0.34	0.25
FeO	0.27	—	—	nil	—	nil
TiO_2	0.06	—	—	nil	—	—
F	3.66	3.55	4.11	2.80	3.71	5.60
Cl	nil	tr.	nil	nil	nil	0.03
H_2O+	1.18	3.16	1.14	0.66	0.46	1.51
H_2O-	1.02	0.54	0.04	0.06	0.01	0.16
Others	—	0.77	0.24	2.19	1.83	0.10
	101.92	102.22	101.79	100.71	101.92	102.66
O for F.	1.54	1.49	1.73	1.18	1.56	2.36
	100.38	100.73	100.06	99.53	100.36	100.30

A. Francolite, Milburn, Otago; F. T. Seelye, Analyst.
B. Francolite = grodnolite, near Grodno, Poland; W. Wawryk, Analyst (McConnell, 1938A, p. 6, Table 2, analysis 2).
C. Francolite = staffelite, Staffel on Lahn, Nassau, Germany; R. B. Ellestad, Analyst (McConnell, 1938A, p. 6, Table 2, analysis 8).
D. Francolite, Robin Hood Quarry, near Leeds; H. C. G. Vincent, Analyst (Deans, 1938, p. 137).
E. Francolite, Wheal Franco Mine, Buckland Monachorum, Tavistock, Devon; E. B. Sandell, Analyst (Sandell, Hey and McConnell, 1939, p. 399).
F. Francolite, Farm Annisfontein, Richtersveld, Namaqualand, Cape Province; C. J. Liebenberg, Analyst (de Villiers, 1942, p. 445).

TABLE 3.

Atomic Ratios in Francolite.

	Wt. %.	Mol. ratios.		Atomic ratios.	Atoms to 26 (O.OH.F.).		
CaO	51.30	9.148	Ca	9.148	9.419		} 10.003
Na_2O	0.46	0.074	Na	0.148	0.152		
K_2O	0.17	0.018	K	0.036	0.037		
CO_2	3.20	0.727	C	0.727	0.748	{ 0.395	
P_2O_5	34.63	2.438	P	4.876	5.020	{ 0.353	} 6.000
SiO_2	2.27	0.378	Si	0.378	0.389		
Al_2O_3	1.18	0.116	Al	0.232	0.238		
F	3.66	1.926	F	1.926	1.983		} 3.332
H_2O	1.18	0.655	OH	1.310	1.349		
			O	—	22.665		
					42.000		

The formula for francolite would approximately be:—

Considering the amount of fluorine present, the figure for H_2O given off above 105° C. appears to be very much too high and is certainly not wholly water of constitution. In the case of dahllite, McConnell (1938B, p. 301) suggests that water obtained above 300° C. is present as OH-groups, but that the amount of water obtained between 110°–300° C. is, to some extent, dependent on the texture of the mineral and is greatly affected by the way in which the sample has been prepared. This water, McConnell believes, is not present as OH-groups in the lattice. From the calculations shown in Table 3, it seems likely that constitutional water would not exceed about one-eighth of the water given off above 105° C., if the number of (OH,F) atoms is to be 2.

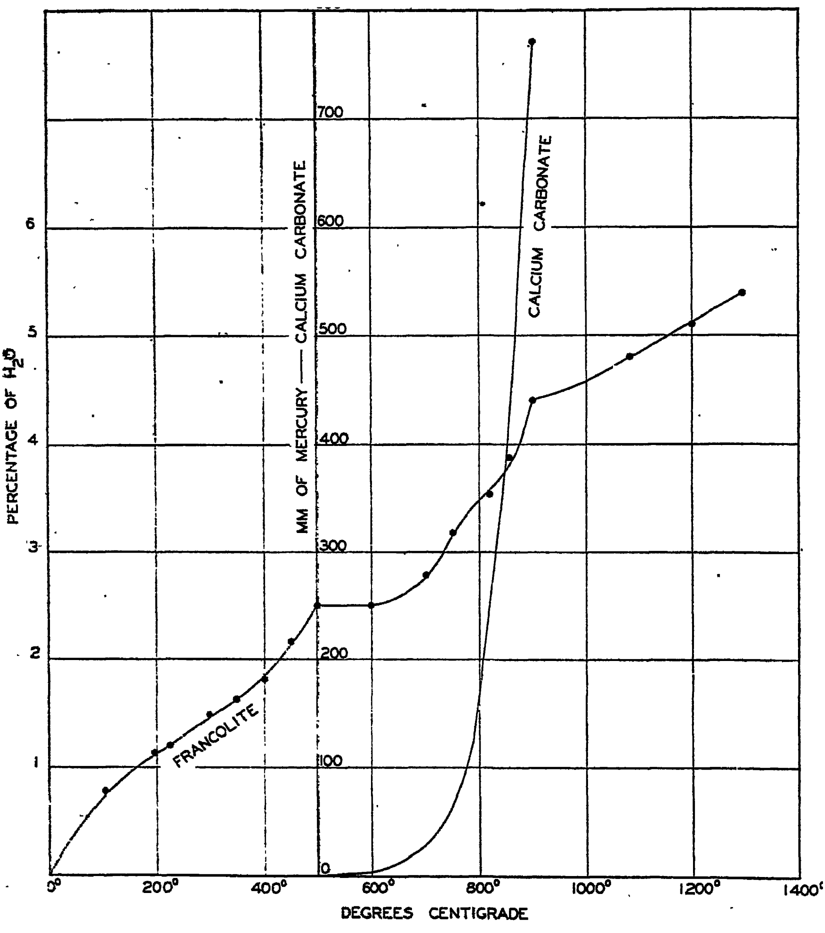

FIG. 1.

Curves showing loss on ignition of francolite (H_2O and CO_2), and dissociation pressures of $CaCO_3$ at given temperatures. The points at 1200° and 1300° on the francolite curve are approximately ± 100° C.

With a view to obtaining some information as to the condition of the water in francolite at various temperatures, a dehydration experiment was carried out and the results are represented in text-figure 1. In the experiment only 0·3 gms. of pure francolite was available after the main analysis had been completed; hence, because of this small quantity, it was only possible to find the loss of weight of francolite on heating and not the weight of water evolved at the various stages. Therefore, while fully aware of the complication introduced because of loss of CO_2 in addition to water, the writers record this data, because, as future workers obtain more information on the carbonate-apatites, some more exact interpretation of the curve may be possible. However, it may be pointed out that at a temperature of 500° C., the loss of weight is 2·5%, that is 0·3% in excess of the weight of total water in the mineral. Therefore, it would seem that even at 500° C. some CO_2 must have been released from the francolite.* This point is of interest because a study of the dissociation pressures of $CaCO_3$ at given temperatures indicates the very small amount of CO_2 evolved at low temperatures such as 500°–600° C., when the carbonate is heated for brief periods. Not until a temperature of 800°–900° C. is reached is CO_2 given off in large amount. This seems to be evidence against the possibility that the carbonate-apatites in general, and francolite in particular, are a mixture of $Ca_{10}\,P_6\,F_2\,O_{24}$ and $CaCO_3$, as the theories of Machatschki (1939) and Thewlis, Glock and Murray (1939) demand.

The platform between 500°–600° C. may be significant, but unfortunately the writers do not know what percentage of CO_2 has been driven off from the francolite. Nevertheless, a study of the CO_2 curve (text-fig. 1) and the curve obtained by heating francolite suggests that the amount of OH present in the lattice of the Milburn francolite is very small.

PETROGRAPHY.

The phosphorite is a pale yellow or buff-coloured rock, composed chiefly of well-rounded and strikingly polished grains of quartz, albite and minor glauconite set in a cement of crystalline francolite. Microscopically, however, it is seen that these minerals are associated with stained prochlorite, green hornblende, sphene, ferruginous epidote, clay, fragments of quartz-albite-epidote-muscovite-schist and some fossil material. The rounded grains of quartz and albite are associated with smaller, but less well rounded grains of the same minerals (text-fig. 2A); the average grain-size is 0·5–0·7 mm. Practically every granule of quartz shows very marked undulatory extinction and, in some cases, even incipient fracture.

The crystallography of the francolite has been described earlier, and it is only sufficient now to describe the microstructure. At least three modes of occurrence, each with transitional stages, are to be seen.

(1) As narrow crusts of prismatic crystals of francolite, up to 0·1 mm. in width, radially directed towards the plane of accumulation and surrounding minerals.

* It is possible that some of the loss of weight may be the result of expulsion of SiF_4.

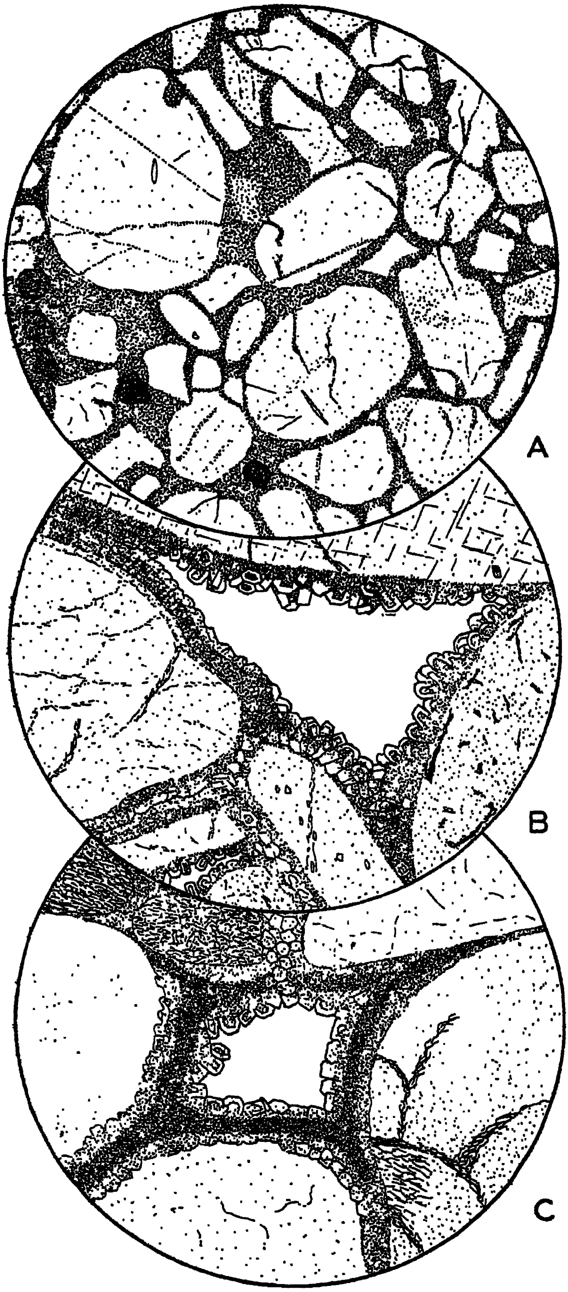

Fig. 2.

A. Grains of quartz, with some albite and glauconite set in a finely crystalline base of francolite. X 24.

B. A geode-like form of crystals of francolite radiating outward from quartz and albite. X 105.

C. A geode of francolite between quartz grains; also some areas completely filled by francolite adjacent to grains of glauconite. X 105.

(2) As geode-like structures due to radial growth of francolite crystals inwardly towards cavities between adjacent groups of quartz and feldspar grains (text-fig. 2B and C).

(3) As areas of dense aggregates of crystalline francolite formed by the complete filling up by phosphate of the geode-like structures mentioned above (text-fig. 2C).

This mode of occurrence of the phosphate mineral is closely similar to that described by Bushinsky (1935, p. 86) in the Cenomanian Phosphorites of the Briansko-Kurski district of Russia.

The heavy mineral residues with a specific gravity > 3 were separated from the phosphorite and the grain-count was found to be as follows: garnet (mostly pink) 12, epidote 34, clinozoisite 3, sphene 38, tourmaline 1, zircon 12. Microchemical tests made on three garnets gave positive reactions for manganese. A study of the main and accessory constituents of the Milburn phosphorite makes it clear that the Otago Central schists have supplied practically all the detritus for these sediments. Strained and fractured quartz, a sodic feldspar, in this case nearly pure albite, fragments of quartz-albite-epidote-muscovite-schists, and all of the heavy residue minerals are essentially common to the Otago schist area. The question of the origin of the phosphatic material has been dealt with by other workers.

CONCENTRATION OF PHOSPHATE.

A number of experiments have been carried out in order to determine to what extent francolite may be concentrated by light crushing and screening. The clue to the problem is to be found in a comparison of the grain-sizes of the chief components of the phosphorite, viz. of quartz and albite, and of francolite. The average diameter of the quartz and albite is 0·5–0·7 mm., while the francolite crystals do not exceed 0·06 mm. in length. With gentle crushing or rubbing by such means as passing between rollers and subsequent screening through 90-mesh and 200-mesh sieves, a notable concentration of francolite results. Thus, when the original phosphorite containing 12.5% P_2O_5 was crushed and screened through 200-mesh, 23% of the crushed material was passed. A quantitative analysis of this product indicated 24% P_2O_5. Investigation of the material remaining on the 200-mesh screen proved that further careful crushing yielded more concentrate with approximately the same P_2O_5 content. Similar operations were carried out using a 90-mesh sieve, and in this case 31% of the material passed through, and this was found to have a P_2O_5 content of 21%. Crushing tests on a specimen that had been naturally baked (P.4187) by overlying igneous rocks appeared to indicate greater friability than in the case of the unbaked material. Therefore it is suggested that initial roasting of the phosphorite might facilitate a more complete separation of the mineral particles on crushing, resulting in better concentration of francolite.

Thus it is evident that the arenaceous phosphorite of the Milburn-Clarendon areas might, by careful crushing and screening, supply a product with at least a content of 80% of francolite (28% P_2O_5). However, it is of economic importance to remember that the phosphate mineral is francolite with a maximum P_2O_5 content of 35%, whereas in the case of Nauru Island or Ocean

Island phosphatic material, the maximum P_2O_5 value obtainable would be about 39–40%, while an analysis of a typical guano from Christmas Island shows 39–44% P_2O_5. On the other hand, when apatite is the raw material used, such as that from the Kukisvumchorr or Yukspor mines of Northern Russia, the P_2O_5 percentage reaches 41–42%.

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The Geology of the West Coast from Abut Head to Milford Sound.

PART 2. GLACIATION.

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SUMMARY.

THE Pleistocene geology is discussed with special regard to the composition and shape of the moraines, which extend from the foot of the Alps to the sea. A marine Pleistocene deposit is described, and a map presented showing the correspondence between the glaciated alpine valleys, when freed from Recent gravels, and the Southland Fiords.

HISTORICAL INTRODUCTION.

Every geologist who has visited South Westland has been impressed by the height and extent of the moraines. Haast stated (1879, p. 93) that " if anything will give the geologist an insight into the power which glaciers have of destroying gigantic mountains, and of carrying their debris away into lower regions, a journey to that part of the West Coast will easily effect this object." The moraines were first described in 1868 by Hector, who published an account of the coast and harbours between Milford Sound and Hokitika. He gave a rough account of the rocks, recognized that the ridges and hummocks along the coast between Bruce Bay and Abut Head were morainic accumulations, and concluded that their rounded form was due to their having been submerged since formation.

In 1877 MacFarlane described the valleys of the Jackson and Cascade Rivers in South Westland and remarked on the thick bed of conglomerate that forms the Cascade Plateau; but he was unable to explain its origin.

The greater part of South Westland was described in a report on the Westland district presented by Cox in 1877. The direct relation between the morainic accumulations and the higher part of the Alps was remarked on in this report (p. 85) where he stated that the glacial drifts " occur largely in a district radiating from Mount Cook, and form all the bluffs from the Mahitahi north, having evidently in former times been the lateral moraines of glaciers which have long since retreated."

Haast's detailed description of the coastal moraines was published in 1879. This masterly account contains a wealth of interesting and valuable detail together with many important generalizations. Further north, in areas actually outside that discussed in this paper, Bell and Fraser (1906) and Morgan (1908) mapped and discussed the northern extension of the South Westland moraines.

The Cascade River district was mapped and described by Turner (1930), who recognized that the peculiar drainage pattern of this plateau was controlled by successive accumulations of lateral moraines. He maintained that these moraines overlie the conglomerate, which he held to be of late Pliocene age.

GLACIAL TOPOGRAPHY.

The glacial topography is discussed in two parts:—

1. Topography caused by glacial erosion.
2. Topography formed by glacial deposition.

1. *Topography caused by glacial erosion.*

In this paper it is not proposed to discuss the glaciation of the Southern Alps proper, but merely that of the lower land west of the Alpine Fault, the position of which has been described in the first part of this paper. The rounded, beehive-shaped hills standing above the lower land are the most conspicuous glaciated features of this area. They extend for many miles north of the area discussed here and are wholly or partly composed of granitic or gneissic rocks. They were probably shaped by a combination of the following processes:—

(a) Normal weathering of massive granitic rocks.
(b) Differential erosion of an area composed of greywackes and argillites intruded by granites.
(c) Glacial erosion.

It is probable that as a result of normal differential erosion the more resistant parts of these areas of granitic, gneissic, and hornfelsic rocks became isolated from one another and more or less rounded before the advance of the ice, and that when the area was invaded by ice they were further rounded by ice action. If this were the case, then the top of the ice must have been more than 2,000 ft. above present sea-level and the ice must have had considerable erosive powers away from the mouths of the alpine valleys, for Mount McLean and Mosquito Hill are well rounded and over 2,000 ft. high. The hills do not generally lie opposite the mouths of the valleys.

Similar granitic hills occur at Lake Manapouri, and similar but smaller hills lie close to the terminal faces of the Franz Josef and Fox Glaciers; these latter have almost certainly been overridden by ice in comparatively recent times.

Many of these hills have been enumerated in the first part of this paper in the discussion of the igneous rocks, and many of them, particularly in the southern part of Westland, must have formed islands when the ice retreated, but have since been connected with the mainland by the formation of the Westland gravel plain.

2. *Topography formed by glacial deposition.*

The long smooth ridges which slope at a gentle grade towards the sea (see plate 16) form the most striking feature of the West Coast moraines. These sloping ridges usually extend from the eastern margin of the morainic material, usually close to the scarp of the Alpine Fault, right to the sea, where they end, generally, in cliffs. It is clear that they once extended some distance beyond the present coastline, and that they have been cliffed back by wave attack to their present position. The characteristic shape is well shown by the moraines that enclose the Cook River Flats, which can be viewed to advantage from the Waiho Gorge-Weheka Road a few miles north of Weheka. (See plate 16, fig. 1.)

The characteristic slope is also well shown by the moraines that form the following bluffs (heights approximate):—

Abut Head		Otorokua Point ..	81 ft.
Waitaki Bluff		Malcolms Knob ..	428 ft.
Kohuamarua Bluff		Karangarua Bluff ..	171 ft.
Blanchards Bluff		Heritaniwha Point ..	294 ft.
Waiho Bluff	256 ft.	Cascade Point	
Omoeroa Bluff	149 ft.	Awarua Point	
Galway Point	465 ft.	Long Reef Point	
Gillespies Point ..	70 ft.		

Some of these are illustrated on plates 15 and 16.

The main external and internal features of the moraines are:—

1. A seaward slope of from 2°–5° presenting an even profile when viewed from a distance, but somewhat irregular when examined in detail, and often with flattish parts rising a few hundred feet above the general level.

2. The moraines form the interfluves of the rivers and some extend from the bedrock at the scarp of the Alpine Fault to the sea, but more terminate 3–4 miles west of the scarp.

3. Terraces closely parallel to the upper surface extend for considerable distances along the sides of some of the moraines. These are well developed north of Cook River and on the sides of the Cascade Plateau, where they have been described by Turner (1930).

4. The moraines decrease in height from a maximum of 1500–2000 ft. at their eastern boundary to 100–400 ft. at the sea coast.

5. At several places near the coast, namely Mount One One, Omoeroa Bluff, and Malcolms Knob, the moraines instead of maintaining their regular grade rise steeply to form promontories. This may be due to cliffing having extended back to an unusually large rise in the morainic surface.

6. The cross-sections of the moraines as exposed on the coast show that they are in general convex, with no great area of flat top and sides which differ considerably in steepness.

7. The layers of material that form the moraine are generally sub-parallel to the surface of the moraine.

This last feature is so general and so peculiar as to deserve special mention. It was first observed by Haast (1879, p. 394 and plate 8), who described this section of the coast as "a true lateral moraine consisting of the usual detrital matter, blocks of all sizes embedded in sand and silt, the whole having a rough anticlinal arrangement.'* On the next page, while discussing Puerua Bluff, he states that this bluff "has at its southern extremity also the rough anticlinal arrangement peculiar to lateral moraines." The anticlinal arrangement is well shown by the narrow, steep-sided moraines, but in all there is a rough parallelism between the top of the moraine and the bands of till, gravel, sand, and silt of which they are composed.

A knowledge of the origin of this feature is essential to an understanding of the conditions of deposition of the moraines. The deposition of sub-parallel layers of moraine upon an irregular surface by successive ice advances is regarded as a reasonable explanation.

The following alternative explanations were considered and rejected.

1. Folding of previously level layers by regional compression. Folding upon such a small scale and in such an irregular manner seems improbable, without considerable associated faulting; and no large scale faulting was observed.

2. Slumping due to melting of sub-adjacent ice. The effects of the melting of sub-adjacent ice were observed both on the moraines of the present-day glaciers and at some horizons of the old moraines. In both cases they were associated with numerous, small, closely spaced faults.

3. Dumping of morainic material from icebergs upon an irregular surface. No marine organisms or obviously marine gravels were seen in the main body of the moraine, and at Omoeroa Bluff, a peaty layer of definitely terrestrial origin extends a few feet above present sea level.

The highest part of the moraines gives a minimum height for the ice sheet and their gradual slope suggests that the base of the ice sheet sloped seaward at a low angle. The present alluvial-filled river valleys represent areas of thicker ice where little or no moraine was deposited, and are not considered to be formed by post-glacial erosion of the moraines. There is no good evidence for the height of the top of the ice sheet; but Omoeroa Hill (2,237 ft.) and Mount McLean (2,400 ft.), both glaciated, suggest a minimum height of at least 3,000 ft. above present sea-level for the top of the ice near the Alpine Fault. Moraine does not appear to have been deposited under the thicker part of the ice sheet immediately west of the Alpine Fault, but was confined to the thinner, seaward part of the sheet. Lakes and alluvial-filled depressions now mark the area that was once occupied by thick ice.

The method of morainic accumulation under the thinner ice appears more closely comparable with continental glaciation than alpine glaciation, in that the supply of material was smaller and the rate of deposition less.

Haast (1879, p. 394) maintained these moraines to be "true laterals," an explanation that may be correct for the comparatively narrow moraines on the Cascade Plateau that flank the Cascade Valley (Turner 1930). Such an explanation is unsatisfactory for the enormous body of moraine to the north of the Cook River. The bedding of these moraines shows that they have been formed by successive addition of roughly horizontal layers, not by successive accumulation of lateral moraines.

Similar Morainic Topography in New Zealand.

Topography that appears to be similar to that characterizing the moraines of South Westland has been described from Preservation Inlet district by McKay (1896), Benson (1933), and Benson, Bartrum, and King (1934). Overlying morainic material has been described by McKay (1896, p. 37), who states that the glacial drifts "on Coal Island form fully three-quarters of the area of surface rock, and are also largely developed at Gulches Head Peninsula, and to a lesser extent between Te Whara Beach, the Neck, and Southport. On the long, gentle slope from Treble Mountain they are in part developed to heights corresponding to those at which they are found

on the eastern side of the inlet, while inland of Landing Bay, near Cape Providence, their presence has been reported, and it is possible that they attain to somewhat similar heights to the north of Chalky Inlet, to those reached between Cromarty and Wilson River." The localities mentioned above by McKay and described as having a varying thickness of morainic covering are figured by Benson, Bartrum, and King (1934, plate 3).

The long, gentle, coastward slope mentioned by McKay (1896, p. 37) and clearly illustrated by Benson, Bartrum, and King's sketches (1934, plate 3) is similar to that of the South Westland moraines. Benson considered this coastward sloping topography as evidence for the presence of a coastal plateau and evidently thought that the moraines had been deposited without much modification of the pre-existing topography. The writers, however, maintain that the strong resemblance between the Preservation Inlet and Westland areas both in topography and glacial deposits is suggestive of a similar, late geological history.

Further north, the Cascade Plateau, which is similar to the more northerly moraines, has been held by Benson, Bartrum, and King (1934, p. 65) and by Benson (1935, p. 399) to be the remnant of an incompletely removed delta that once filled the pre-" Coastal Plateau " valleys, and across which the " Coastal Plateau " was cut. Benson (1935, p. 399) states that this " explanation involves the probability that remnants of incompletely removed deltas might occur high above the mouths of their parent streams. An excellent example of this is afforded by the Cascade Plateau, occurring 20 miles north-east of the limits of Fiordland proper, where a large, gently sloping remnant of a former delta stands beside the mouth of the Cascade River at a height of 1,000 feet or more, quite comparable with that of the coastal plateau."

Turner (1930), largely because of the induration of the material, concluded that the Cascade Plateau was formed of a veneer of moraine overlying a thick series of late-Pliocene conglomerates. The writers do not agree with the age or origin assigned to these conglomerates by Turner or Benson, for they are very similar to the undoubted moraine exposed on the coast both north and south of the Cascade Plateau and they rest upon smooth and rounded gneisses and hornfels which are well exposed close to the track between the Martyr Bridge and the Cascade Hut. Furthermore, at several places along this track where the overlying material has only recently been removed, well marked, sub-parallel grooves were observed. These were parallel to the adjoining part of the Cascade River, which flows at 10° east of north. It seems almost certain that they are glacier striae cut by the eastern side of the Cascade Glacier which later deposited both the " Conglomerate Series " and the overlying moraine, and that the Conglomerate Series and the overlying moraine are not separate beds, but that both form part of a thick glacial deposit of about the same age as those described to the north and to the south. The large proportion of serpentine in the Cascade moraine is held to cause the induration of this deposit, for similar induration has been observed with recent serpentine conglomerates at D'Urville Island and North-West Nelson.

In the Martin Bay district, Healy (1938) described a coastal plateau which he correlated with that described by Benson in the Preservation Inlet area to the south and with the Cascade Plateau to the north. Healy (1938, p. 84) maintained that the large morainic boulders distributed over the surface of this coastal plateau are part of a widespread but thin deposit. In this district is Awarua Point, which, when viewed from the south across Big Bay, appears similar in profile to the moraines to the north and has a seaward slope of about 2°. It is convex in cross-section and shows signs of terracing on the south side. Moraine may reach a thickness of 200 ft. on the top of this point, but is represented at sea level only by erratics, which are strewn over the surface of a slightly uplifted bench that the sea has cut in the projecting end of this point. This platform has been cut in the Tertiary rocks upon which the moraine rests further inland. A similar sloping surface has been illustrated by Healy (1938, fig. 4) extending back from Long Reef Point, between Big Bay and Martin Bay, to Sara Hills. Morainic boulders similar to those at Awarua Point veneer a coastal bench for about a mile along the southern side of this point. The surface of both Awarua and Long Reef points is regarded as a part of the coastal plateau by Healy.

It will be seen that similar, seaward-sloping land-forms constitute a conspicuous feature of the topography of the West Coast from Ross southwards to Bruce Bay, from the Cascade Plateau to Milford Sound and in Fiordland south from Resolution Island. They appear to be absent between Bruce Bay and the Cascade Plateau and between Milford Sound and Resolution Island. Their absence between Milford Sound and Resolution Island is probably due to the Alpine Fault, which has caused deep water to lie off the high land to the east. Their absence between Bruce Bay and the Cascade Plateau is more difficult to explain, but is no doubt connected with the almost complete absence of moraines in that district.

Source and Significance of the Dissimilar Morainic Materials.

The proportion of metamorphic rocks in the moraines increases southwards as has been noted by most of the early workers in this area. Some have ventured an explanation. Hacket (1868, p. 9) stated that in the moraines of the Okarito district "micaceous rocks are however very scarce although they are abundantly found *in situ* a few miles inland at the heads of the rivers. They are of more common occurrence, however, in the moraines near Cooks River, where the mountains approach nearer to the coast." Cox (1877, p. 85) commented on the composition of the moraines and stated that "they are composed chiefly of Maitai and auriferous slates and sandstones mixed, however, with the metamorphic rocks which are more plentiful the further we go south, and some blocks of which could not weigh less than 10,000 tons." The same writer (*idem*, p. 86) also noted the presence of volcanic rocks, which he regarded as having been derived from volcanics at Paringa and which he stated "points to the fact that during the period of greatest extension of the glaciers the great centre of elevation was from a point south of Mount Cook." Haast (1878, p. 393–4) commented upon the absence of true meta-

morphic rocks in the moraines at Bold Head and Wanganui Bluff, and pointed out that the presence of such rocks in the alluvial deposits that separate the moraine into two distinct parts are evidence of "the retreat of the glacier to such a high position, that the lower slopes of the Alps were exposed to glacial and fluviatile action." The same writer observed (p. 393) that "towards the south the metamorphic rocks become gradually more numerous."

An outline of the basement geology is necessary to understand the origin of the moraines. Somewhat similar greywackes and argillites lie both to the east and west of the belt of metamorphic rocks that extends along the western side of the Alps as far south as Jackson River. The western greywackes and argillites, classed by the writers with the Greenland series, have been intruded by granites, and extend as a coastal strip, flanked, however, by Tertiary rocks as far south as Milford Sound. The eastern or Alpine Greywackes extend east of the metamorphic rocks and form part of the west side of the Alps only as far south as the headwaters of the Haast River, from which point south to Jackson River the entire western slopes of the Alps are composed of metamorphic rocks. Consequently the headwaters of rivers as far south as the Haast lie within the Alpine Greywackes, although to decreasing amount as we go south. The snowfields of the present glaciers also lie within the Alpine Greywackes and although the glaciers pass through the metamorphic belt, the greater part of their moraines is composed of Alpine Greywacke as is the gravel in the rivers which drain them.

Between the Waiho and Cook Rivers the moraines can often be divided into two parts, an upper, consisting of predominantly metamorphic rocks, and a lower, of predominantly greywacke. Further south where the western side of the Alps is mostly schist, such a distinction cannot be drawn.

It is probable that the glaciers have always moved away from the mountains and almost directly towards the sea, and that the materials in the moraines have been derived from the mountains to the east. If this is the case, then the change in the composition of the moraines must be a reflection of the composition of the area where glacial erosion was greatest at that time, and the change from Alpine Greywacke to schist suggests that glacial erosion was first concentrated at the eastern greywacke areas, then moved west to the metamorphic belt, and finally as shown by the present glaciers moved back to the greywacke belt. It is not clear how this change took place, but it is difficult to understand unless there has been some elevation of the schist belt.

This schist belt now forms the seaward-facing scarp of the Alpine Fault, and has been elevated several thousand feet relative to the land to the west. A small part of this elevation would serve to account for the changes mentioned above, and evidence for recent movement along this fault-line has been given in the first part of this paper (1942, p. 292). If the schist belt has been elevated during the Pleistocene, then the following sequence of events is not improbable. The glaciers, when they advanced in the pre-Pleistocene valleys, eroded most at their heads well back in the greywacke belt, there being less erosion in the flatter, lower parts of the valleys, the moraine

deposited by these glaciers was then largely composed of greywacke. Movement then took place along the Alpine Fault; and, over the fault-scarp thus formed, the glaciers plunged as ice falls till erosion along the schist belt re-established the grade of the surface of the glaciers. At this time the glaciers carried mostly schistose rocks to the sea. A possible further small movement along this fault may have taken place also during the retreat of the ice; for, although the beds of the present glaciers at the fault-line are close to or below sea level, the valleys do not seem wide enough to accommodate glaciers that could either extend to the sea or deposit the extensive moraines previously described, and it seems likely that the older, larger glaciers must have had wider valleys. These valleys were probably also cut down to sea level at the fault-line, but have since been elevated, and may now be represented by the upper broader parts of the present valleys. This last elevation does not seem to have extended far south of the highest part of the Alps, for the glaciated Karangarua Valley and most of the other valleys to the south are much wider than those of the present glaciers, and show no signs of recent elevation.

Glacial Deposits.

The glacial deposits described cover the larger parts of two areas, the more northerly and larger extending north from Blue River beyond the area described to Ross, and the other as a veneer over the coastal parts of western Otago and as a deposit comparable in thickness with the northern area from Sandrock Bluff to the Cascade Plateau. The varved silts, which are often associated with the other morainic material, are described separately in the following accounts of morainic sections.

Coastal Sections.

Hackett (1869) was the first to describe the cliffs between Waitaki and Cook rivers in any detail. He stated (*id.*, p. 10), "in some places the whole mass of the morainic matter has a stratified appearance, which is pretty distinct when viewed from a distance. In other places are stratified beds, of limited extent, but very decided." Haast later (1879) gave a fairly detailed description of the morainic sections exposed along the coast from Bold Head south to Heritaniwha Point. In his description of the Bold Head section (1879, p. 393), he noted the "existence of an alluvial deposit 30 to 40 feet thick having a considerable slope to the south and separating the morainic beds into two distinct proportions." The same writer (p. 393) stated that the material making up the moraines at Bold Head is "derived from the Mount Torlesse and Waiho Formations, typical metamorphic or igneous rocks being of rare occurrence." Morgan (1908) mapped the northern part of the morainic coast, but did not add to Haast's detailed descriptions.

Omoeroa Bluff to Galway Beach.

Omoeroa Bluff forms the seaward extremity of a small moraine lying between the Waiho and Omoeroa Rivers. At the north side of the bluff the following section is exposed at the coast:—

10 ft. of fairly hard till containing rounded to sub-angular cobbles of greywacke with little schist or granite.
Erosion break.
25 ft. of sandy varved silts containing rounded and subangular boulders of greywacke with occasional lenses of well rounded gravels.

At the south end of the bluff the exposed section is thicker and shows:

20 ft. of sand and gravel layers interbedded in a hard till. The gravel ranges from 3–6 inches and is practically all greywacke.

6 inches of ancient peaty soil containing lumps of woody material, some of which is changed to lignite and some almost unaltered.

The upper 100 ft. of the bluff lies above the sections described and is composed of coarse angular boulders of greywacke set in a sandy till and partly hidden by vegetation. Numerous, large, subangular boulders of greywacke lie on the beach below the bluff. They are the unconsumed remnants of the previous, seaward extension of the moraine. Similar boulders, many of huge size, form small islands off the ends of most of the bluffs, being particularly well developed opposite the highest morainic cliffs, those at Galway Point.

To the south of Omoeroa Bluff moraines are next exposed on the coast at Neds Creek, 7 miles south of Waiho River, and from this point to Otorokua Point, a mile north of Cook River, the moraines are unbroken by large rivers and generally form cliffs along the coast. Between Omoeroa Bluff and Neds Creek the moraines do not reach the sea, but are separated from it by a triangular area of gravel through which the Omoeroa and Waikukupa rivers flow in their lower reaches. The morainic cliffs are not confined to the present coast; for, both north and south of Neds Creek, cliffs extend back behind beach gravels and show that marine cliffing has been followed by marine deposition and retreat of the sea. This has taken place without obvious change of sea level and is due to the sea having rapidly modified the irregularities left by the retreat of the ice. The sea being supplied by the rivers with vast quantity of gravel, soon formed the present mature coast. The high, continuous, morainic cliffs between Neds Creek and Otorokua Point represent deposits of the glaciers which advanced furthest from what is now and was probably then, the highest part of the Alps. Moraines along this part of the coast consist of fine, bedded silts, sand, and gravel together with cobbles and boulders of greywacke and schist. The proportion of schistose rocks is greater than at Omoeroa Bluff and represents over 40 per cent. of the moraine, occasional granite cobbles being less weathered than at Omoeroa Bluff.

The small streams that drain the swampy surface of the moraine discharge over the cliffs as waterfalls with little erosive power, for these falls are covered with vegetation and no fresh rock is exposed. The larger streams have, however, caused some modification of the face of cliffs; but have not, as might be expected, graded courses, but fall vertically from the top of the cliffs down the side of hollow vertical cylinders eroded out of the moraines and enter the sea through comparatively small gaps in the fronts of these cylinders. These features are probably due to the streams eroding an unconsolidated stratum at the base of the cliff and undermining the more compact, cemented material on the surface and front of the cliffs.

Morainic cliffs extend the entire length of the coast from Neds Creek to Gillespies Point, jutting out into the sea at Galway Point.

At Galway Point the following section exposed in the cliff face was noted:—

40 ft. (+) Well-consolidated till, containing cobbles and small boulders of greywacke and schistose rocks. No large boulders. Schistose rocks and greywacke rocks in equal proportions. The cliff above extended another 200 feet and appeared to be of similar material.

20 ft. Grey-white till, containing angular boulders up to four feet of non-schistose greywackes and schistose rocks.

20 ft. Horizontal sandy micaceous layers with a six-inch interbedded layer of well-rounded gravel. Here and there an odd boulder of schistose rocks.

20 ft. Till containing fairly well-rounded cobbles of greywacke, but a marked absence of any large angular boulders. The general appearance of this moraine is much more weathered than that overlying and in particular the occasional granitic cobbles are fairly well decomposed.

Along Galway Beach, which lies between Galway Point and Gillespies Point, the between-tide beach at the base of the cliffs is covered with huge, sub-angular, schistose boulders up to 20 feet in diameter. Greywacke boulders are rare along this part of the beach.

Gillespies Point.

Gillespies Point is the seaward projection of the moraines that extend from the Cook Saddle, about 12 miles inland, in a westerly direction toward the coast. (Fig. 2, plate 16.)

The moraines represented at the point are composed of a well-consolidated till containing rocks largely derived from the greywacke of the Greenland Series, schistose rocks being rarely represented.

At Gillespies Point, the moraine forms a long, curved embankment, having a triangular cross-section which is a striking feature of the topography.

Otorokua Point.

At Otorokua Point, two moraines composed of dissimilar material can be seen in contact. The line of junction between the two moraines dips to the south at 30°, being parallel to the rude bedding of the upper moraine, and truncating the bedding of the lower. Hence it may be regarded as a morainic unconformity.

The Point rises about 80 feet above sea-level and is a south-west extremity of the moraine immediately north of the Cook-Fox River Flats, of which Gillespies Point is a part.

The lower or older moraine at Otorokura Point is made up chiefly of greywacke pebbles and cobbles together with a few boulders of granitic material and a rare volcanic cobble. The boulders range up to 8 feet in diameter and are embedded in well-consolidated till, composed of the fine silts and sub-angular gravels. Where the silts occur, the bedding observed dipped steeply (45°) to the north. The whole moraine is deeply weathered and decomposed, the granitic rocks in particular showing the effects of weathering.

At the base of the overlying or younger moraine is a layer of fine silt with small gravel lenses all dipping parallel to the contact, that is, to the south, at 65°. These silts truncate the bedding of the older moraine at right angles. The silt-band varies in thickness from three inches to three feet, and at the base of the bluff the dip of the silt flattens. Nearly 95 per cent. of the upper moraine is composed

of schistose rocks, greywackes being extremely rare. This moraine is much less weathered and decomposed than the underlying one, all the schist cobbles and boulders being much more angular and less rounded than the boulders of the lower moraine. Where greywacke predominates in the lower moraine, the upper is almost entirely composed of schistose rocks.

Wave attack along the base of the cliff has removed the till and cobbles, leaving the between-tide beach covered with huge greywacke and schistose boulders, the largest observed being about 20 feet by 15 feet. A boulder of Tertiary sandstone was also noted.

The surface slope on the south side of the moraine at Otorokura Point is parallel to the bedding of the upper moraine and to the silts at the line of contact between the two moraines.

On the north side, the surface is parallel to the bedding in the lower moraine. The junction between the two moraines extends from the top of the cliff to the base.

At several points along the Gillespies Beach-Weheka Road the moraines were observed in road cuttings. Nearer the beach the moraines seen were of the older type, being composed largely of greywacke cobbles and boulders; but eastwards and further inland, later moraines of schistose rocks were noted.

Karangarua Bluff.

The Karangarua Bluff, rising 171 feet above sea-level, immediately to the north of the mouth of the Karangarua River, is the coastal end of a moraine that extends inland in a south-east direction for about six miles and rises in height to 1,424 feet.

The form and composition of the moraine at this point is similar to the others described above, the rocks being largely greywackes with a few igneous cobbles with a rare schist cobble. Haast (1879, p. 395) noted that the Weheka-Karangarua moraine contained some metamorphic and igneous rocks at its northern end. This probably refers to the moraine at Malcolms Knob.

Makawhio Point.

Makawhio Point, formerly known as Jacobs Bluff, forms a coastal projection 250 feet high immediately north of the Makawhio River. The moraine extends from the coast inland to the line of the Alpine Fault, a distance of about six miles, and is separated from the Karangarua moraine by low swampy coastal flats. The till forming this moraine shows a large increase in schistose rocks. In fact, according to Haast (1878, p. 396) "the metamorphic rocks form at Makawhio Bluff the greatest portion of the morainic accumulations." The same writer (*idem*, p. 396) states that at Makawhio Bluff an interesting feature is "the occurrence of an ancient river bed about 20 feet thick, deposited against a lateral moraine, covered by a younger morainic accumulation."

Heretaniwha Point.

On the south side of Bruce Bay, a moraine projects seaward to form Heretaniwha Point, 294 feet above sea-level. (Fig. 1, plate 15.) This moraine presents the typical semi-circular cross-section and is made up largely of schist cobbles and boulders, greywacke rocks being rather rare. The base of the bluff is fringed with large schist and greywacke boulders, derived from the moraine.

From Heretaniwha Point to Cascade Point, a distance of about 60 miles, moraines are entirely absent, with the exception of Jackson Bay, where the between-tide beach is covered with large morainic boulders, which may have been derived from the erosion of the moraines at Cascade Point and transported round the point into Jackson Bay.

Cascade Point.

Coastal moraines form a line of cliffs from Seal Rocks (seven miles east of Cascade Point) to Sandrock Bluff with the exception of Barn Bay, where the Cascade alluvial plains reach the coast. The cliffs from Seal Rocks to the mouth of Cascade River represent the coastal end of the moraine that forms the Cascade Plateau. This plateau extends inland for a distance of about 12 miles to the line of the Alpine Fault.

Mount Iota, between Cascade River and Barn Bay, is a morainic hill extending seaward to form Halfway Bluff.

Another morainic mass forms the coastline from the Hope River south to Bluff Creek, immediately south of Sandrock Bluff. This moraine extends inland for about two miles to Steep Head and forms a series of high cliffs.

McFarlane, reporting on the Jackson River-Cascade River district, described the moraine forming the Cascade Plateau as "a heavy conglomerate showing very complete stratification, having a slight dip to the north-west" (McFarlane, 1877, p. 30). Haast (1879) did not record the presence of any moraines there, but mapped the rocks of the Cascade Plateau as Tertiary.

Charles E. Douglas, in an unpublished and undated map of Westland, shows the Cascade Plateau as being formed of morainic drift, resting directly upon the Maitai Slates. This map also shows a similar plateau to the east of Mount Malcolm, between the Jerry and Gorge rivers, which is mapped as having a cover of morainic material.

Turner (1930) was the first to record the presence of moraine in this area, but he maintained that " the morainic material which covers most of the plateau is actually a relatively thin cover, beneath which lie at least 1,000 feet of rocks belonging to the Conglomerate Series."

For reasons stated in a previous section of this paper, the authors maintain that the morainic accumulations on the Cascade Plateau include what Turner (1930) regards as his Pliocene Conglomerate Series.

As the coastal section at Cascade Point and Halfway Bluff was not examined, the writers are unable to give any descriptions. Further south, however, they examined the coastal section from Barn Bay to Sandrock Bluff.

McFarlane (1877, p. 30) stated " at Teer's Creek, on the coastline, at high-water mark, the underlying rock is exposed consisting of a blue clay, passing into rock," while Haast's map (1879) shows the Tertiary rocks forming a belt along the coastline from Jackson Bay south to Big Bay. Turner (1933) mapped the basement rocks in this area in the Oligoclase zone of the Maniototo metamorphic series. McFarlane (*idem*, p. 28) shows in his cross-sections along the

Cascade Plateau the conglomerates at Cascade Point resting directly upon clay passing into slate. This suggests that the Greenland greywackes may underlie the moraines at this point and that the Middle-Tertiary rocks mapped by the writers (see plate 48, fig. 1, p. 302, 1942) are confined to a belt about two miles wide and were eroded away on the west prior to the deposition of the moraines. The writers regard the presence of Greenland rocks below the moraines at Cascade Point as highly probable.

The moraine of Cascade Point Plateau area is composed largely of cobbles and boulders of ultra-basic rocks, but boulders of schist were occasionally noted. The cobbles are fairly well rounded and the whole is extremely well cemented with a light blue silt. It is so strongly cemented that, at several places on the Martyr River-Cascade track, outcrops of the morainic material are actually overhanging. Turner (1930, p. 527) gave a further description of these deposits and commented on the degree of cementation and the composition of the constituent cobbles. The same writer (*idem*, p. 528) noted that in the section exposed in Teer Creek the beds dip to the south-east at 5°.

Sandrock Bluff.

Sandrock Bluff rises to a height of about 120 feet, and is the most southern point in Westland where thick morainic accumulations reach the sea.

The section exposed shows the following features:—

80 ft. Varved sandy silts, containing lenses of coarse gravel, with occasional schist or ultra-basic angular cobbles.

25 ft. Varved sandy silts, showing contortion and minor faulting. Some lenses of fine gravels and occasional cobbles in the varves.

15 ft. Well-cemented till, containing subangular cobbles of schist and ultra-basic rocks set in a fine-grained grey silt.

The varved silts dip to the south at about 10° and many show well-preserved ripple marks when split along the bedding planes. In some places they exhibit peculiar contortions of the varves in a series of small folds. Each fold was faulted. The beach along the cliff base is covered with huge angular masses of consolidated moraine, and even varved silts are sufficiently cemented to withstand pounding by the waves for a considerable time without disintegrating. There are only a few large boulders of schist or ultra-basic rock. From Barn Bay to Sandrock Bluff, the beach is covered with rounded boulders that have evidently been derived from moraines at the back of these beaches. The majority of these boulders are ultra-basic boulders.

The beach extending south from Madagascar Beach to Yates Point is strewn with boulders up to 8 feet in diameter of igneous and schistose rocks. These must be derived from the covering of moraine that forms a plateau known as the Tableland between the Wolf and John o' Groats rivers. Although this area has not been examined by the writers, it appears to be similar in form and origin to the other morainic-covered, plateau-like areas to the north, such as the Gorge River and Cascade plateaus. The long, gentle, seaward slope of Yates Point, shown by Healy (1938, p. 84, fig. 6) strikingly resembles the long coastward slopes of the moraines to the north.

Varved Silts.

Varved silts were observed at (1) Pug Creek, (2) on the Paringa Haast track, (3) near Moeraki River, and (4) at Sandrock Bluff. The Pug Creek deposit is the most extensive and, being fossiliferous, is of considerable interest.

Pug Creek Varved Silts.

Pug Creek is a small stream that flows in from the north-west to join Omoeroa River about five miles from the sea. Pug Creek has in very recent time changed its course, probably as the result of capture by a small creek eroding headward in the soft silts. The unusually good exposure of these soft beds is largely due to this geological accident. The silts dip to south-west at 10°.

The following is a generalized section of the beds exposed:—

30 ft. Coarse, angular, morainic material composed of schist and greywacke.
30 ft. Varved, sandy silts.
2 ft. Peaty layer, with lignified wood-fragments.
40 ft. Sandy silts passing down into varved, sandy silts.
6 in. Peaty layer.
5 ft. Cross-bedded, marine sands.
60 ft. Fine, varved silts, showing about ten varves per inch.
30 ft. Extremely fine, varved silt, with irregularly distributed fragments of schist up to 6 inches, fossiliferous.
10 ft. Coarse, angular, morainic material, consisting of greywacke boulders up to 2 ft., with smaller, rounded cobbles.
Basement. Greywacke of the Greenland Series.

The fossils are confined to bands in the lower silts, but are not well preserved, having apparently been broken during the compaction of these even-grained beds. The writers are indebted to Mr. C. A. Fleming, of the Geological Survey, for the following determinations and notes.

Three species of marine molluscs are represented, all recent, benthic forms. Their known depth-ranges suggest deposition in water of a minimum depth of about 10 fathoms and a maximum depth of probably no more than 100 fathoms, though the maximum is less definite than the minimum.

1. *Chlamys radiatus* (Hutton).

The form of this species present is comparable with specimens from deep water off Stewart Island rather than from northern localities, but in the absence of full data from recent bottom-faunas off Westland, this should not be taken to imply any post-glacial southward migration.

Depth-range: 13 to 25 fathoms.

Recorded from Preservation Inlet.

2. *Nemocardium pulchellum* (Gray).

Depth-range: 10 to 120 fathoms.

Recorded from Wet Jacket Arm (Preservation Inlet), Milford Sound in 100–120 fathoms.

3. *Eximiothracia* cf. *vitrea* (Hutton).

Depth range: 2 to 15 fathoms, but probably to a greater depth also—evidence is scanty.

All the species require highly saline conditions, none being able to tolerate any degree of freshening; for example, they do not occur in landlocked sea arms that are receiving large quantities of river

waters. Such forms are not present, for instance, in Auckland Harbour, but bottom conditions in fiords seem to be suitable.

A sample of the lower Pug Creek varved silts was examined by Dr. H. J. Finlay, who prepared the following notes on the foraminiferal fauna.

The sample of somewhat greasy siltstone from Pug Creek washed down with some difficulty owing to the very large amount of fine mica. The residue consisted principally of this, which made flotation of the foraminifera impracticable, and a micro-fauna was obtained only after prolonged tapping on a sloping bench. The best that could be obtained was still a poor fauna, of only nine species, as follows:—

Bolivina probably n.sp. (small, slender, with regular, 45°, sloping chambers projecting in blunt spires, somewhat like the Cretaceous *decurrens*, Ehrenb.).
**Bulimina aculeata* d'Orb.
**Cassidulina* cf. *carinata* Cush.
**Cassidulinoides orientalis* (Cush.)
**Nonion* aff. *labradoricum* (Dawson)
**Elphidium advenum* Cush.
**Notorotalia* n.sp. aff. *zelandica* Fin.
Anomalina cf. *parvumbilia* Fin.
**Globigerina* sp. (very small, 5 globular chambers)

This is too small and peculiar a fauna to allow much deduction as to the age and affinities. The species marked with an asterisk all persist to Recent times and all the species were very rare with the exception of the *Nonion* (abundant), *Notorotalia* (9), and *Elphidium* (7). The only age remark that can be made with certainty is that the fauna is not older than Pliocene, almost certainly not older than Waitotaran. Its occurrence between glacial moraines would suggest late Pliocene or Pleistocene age, but there are some discrepant features in the actual fauna. It does not, for instance, compare at all well with a fauna from George Sound, a recent fiord condition fauna; this is quite rich, also has a spiked *Bolivina* (but of the *beyrichi* type), and has a distinctive *Loxostomum kanerianum* (Brady) abundant, a notable feature of all our Recent faunas, when contrasted with the Pliocene. The Castlecliff, late Pliocene, has also a rich fauna, but the spiked *Bolivina* present is as in most later Pliocene faunas, *difformis* (Will.). A striking difference, certainly due to facies, is the abundance of *Miliolids* in Castlecliffian and Nukumaruan faunas. They are not actually common in the Waitotaran.

Although the *Bolivina* is the most striking species in the small fauna, one hesitates to use it too much because of the known likelihood of distinct species of this genus appearing when the facies differ considerably. Yet it cannot be argued that the Pug Creek fauna is different solely because of the icy water conditions; cold water faunas are usually rich, especially in arenaceous species, and the present assemblage does not in the least resemble the communities recorded by Heron-Allen and Earland from Antarctic areas. But it is not essentially different from the 30–40 fathom faunas at present met with, even in the Hauraki Gulf, if one considers that some inhibiting factor prevented the appearance of the *Miliolidae*, *Textulariidae*,

Lagenidae, etc., and left only the hardier, fairly shallow-water forms. Similar, very poor faunas with overwhelming abundance of the same *Nonion* have been seen in the Urenuian and Opoitian, where the sediments were also very micaceous and sometimes carbonaceous, indicating poor conditions for rhizopod life, so that the question of facies must loom large over the whole matter.

A probably more important species than the *Bolivina* is *Anomalina parvumbilia.* This has a wide range of habitat, and is usually a common species from the Hutchinsonian onwards, but has not been observed above the Petane. The Castlecliff and the shallow water Kai-Iwi faunas lack it in all cases seen, rare species are present in the upper and lower Nukumaruan, and it is not so common till the Waitotaran. An extraordinarily rich and varied fauna (300 species) from Martinborough contains practically all the Petane species from a variety of habitats, including some 35 *Bolivinas,* but the Pug Creek *Bolivina* is not there.

Until a larger fauna is obtained, or a match is found elsewhere for the present fauna, it would be hazardous to carry the discussion any further.

Condition of Deposition.

The fossiliferous beds were deposited after an advance of the ice had deposited a predominantly greywacke moraine upon the greywacke basement. This material was either deposited below sea-level, or the land was lowered relative to the sea before the deposition of the 170 feet of fine bedded marine silts. This fine bedded material may represent the infilling of the sheltered landward end of a fiord that was supplied by the finer products of glacial erosion, the upper peaty layers being formed close to sea-level when the infilling was almost completed.

The angular fragments of various types of schist unassociated with other coarse material which are scattered through the fossiliferous beds, are strongly suggestive of materials dropped during the melting of floating ice, and indicate that during this period the ice margin was not far from the sea.

Conditions of deposition are abruptly changed in the upper 30 feet of the section, which is composed of schistose morainic material similar to that at Otorokua Point. This suggests that during or after the deposition of the fine beds glacial erosion had shifted from greywackes, probably those east of the schist belt, to the schist. This change was possibly caused by elevation along the Alpine Fault, exposing the schist belt to rapid glacial erosion.

Varved Silts at Moeraki River.

Varved silts associated with morainic till extend along the Paringa-Haast track immediately north of Moeraki River. They are similar to those at Pug Creek, but are not fossiliferous. They dip to the south-west at 15°. This dip is likely to have been caused by movement along the Alpine Fault, for it is too regular to be a depositional feature.

Varved Silts at Sandrock Bluff.

These beds have been described with the rest of the section at Sandrock Bluff. They are more indurated than any further north, a feature that may be caused by the presence of serpentine rock flour.


FIG. 1


FIG. 2

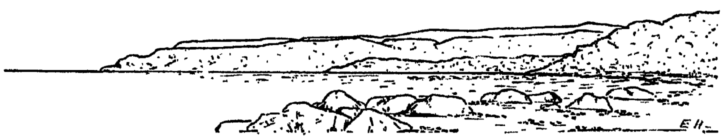
FIG. 3

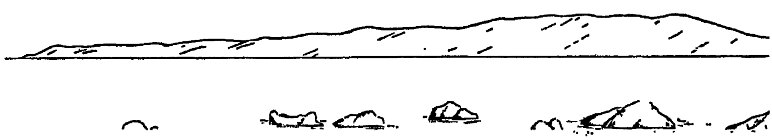
FIG. 4

FIG. 1—Heretaniwha Point, view from north side of Bruce Bay, a seaward sloping moraine on the south side of the Mahitahi River.

FIG. 2—Glaciated granitic knobs near Wataroa, South Westland.

FIG. 3—Longridge Point, view north from the mouth of the Hacket River, a seaward sloping moraine extending from Mount Malcolm.

FIG. 4—Awarua Point, view from south side of Big Bay, another seaward sloping morainic covered point.

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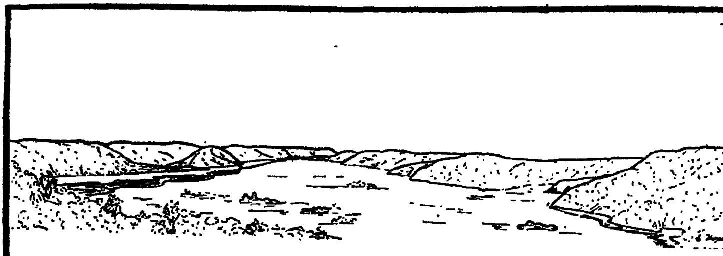


FIG. 1

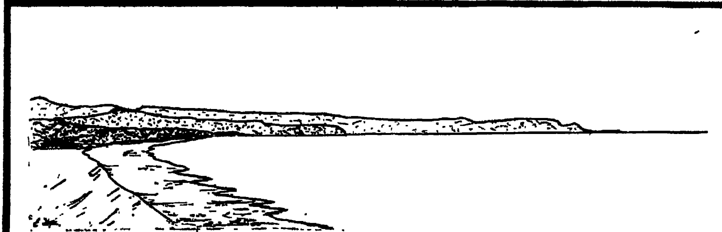


FIG. 2

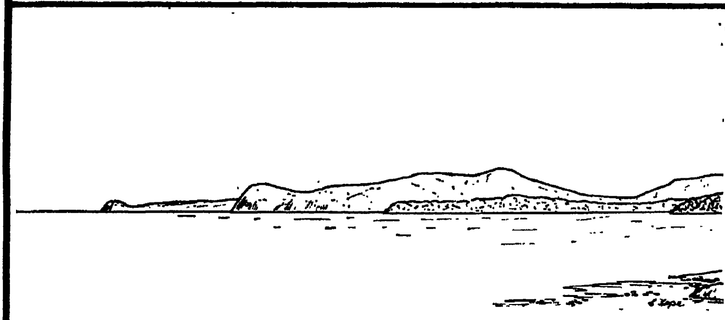


FIG. 3

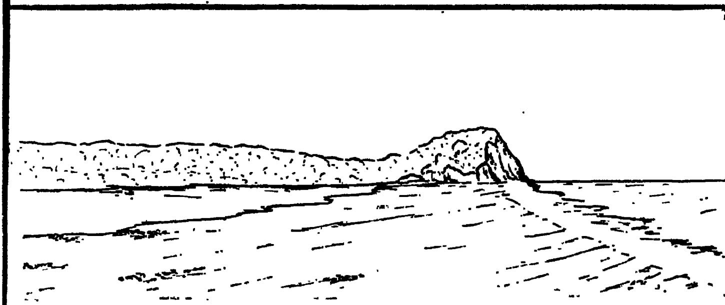


FIG. 4

FIG. 1—View west from the Cook Saddle on the Waiho-Weheka Road, showing the Cook River flats flanked by seaward sloping moraines.

FIG. 2—Gillespies Point, view from Sandfly Beach showing the long seaward sloping moraine.

FIG. 3—View north along coast line from Bruce Bay, showing a series of seaward sloping moraines and morainic cliffs, Malcolms Knob at extreme left.

FIG. 4—Malcolms Knob, cliffed seaward end of a moraine that flanks the southern side of the Cook River Flats.

THE RELATION BETWEEN THE WEST COAST VALLEYS AND THE FIORDS OF SOUTHLAND.

The Southland fiords, Lake McKerrow, and the main valleys of the South Westland rivers are glaciated valleys that differ in original depth and in the amount of post-glacial alluviation. They may be considered as representing stages in post-glacial evolution. The way in which this change is taking place is well shown by Lake McKerrow, which has reached a stage intermediate between the fiords and the South Westland valleys.

The hard gneisses and hornfels on the east side of the lake bear ample evidence of the glacial erosion to which they have been subjected, ice scratched and rounded surfaces being common close to the edge of the lake. The sides plunge steeply below the waters of the lake without change of slope and deltas formed by side streams are small.

Alluviation is taking place at both ends of this lake, at the upper end by delta growth and at the lower end by widening of a bar that has formed close to the seaward end of the old fiord. This bar now has a width of about two miles and is largely composed on its inner side of outwash fans from the sides of the valley. The lake is now so far above the sea that tidal effect is much reduced, but the water is still brackish and the marine fauna not entirely replaced by fresh.

Mr. C. A. Fleming, of the Geological Survey, has kindly prepared the following notes on mollusca collected from the delta at the upper end of Lake McKerrow by Mr. J. Healy in 1937 and on one species found on the beaches at the lower end of the lake by the writers. It is likely that all these species lived in the comparatively recent past when there was connection with the sea.

A. From silts at head of Lake McKerrow, about 10 feet above the present lake level:—

1. *Chione (Austrovenus) stutchburyi* (Gray) (collected by J. Healy).

The specimens are moderately large and have fairly thick shells, suggesting a fairly high salinity, for in brackish, acid water conditions near the limit of tolerance for the species the shells are far thinner and stunted.

Depth range: Half-tide to 2 fathoms, tolerant of low salinity.

2. *Mactra* cf. *rudis* (Hutton).

Found in similar conditions to the above and also with a wide salinity tolerance.

B. Near the mouth of Lake McKerrow, at mouth of Hokuri Creek, found on shingle beaches, evidently derived (collected by the authors):—

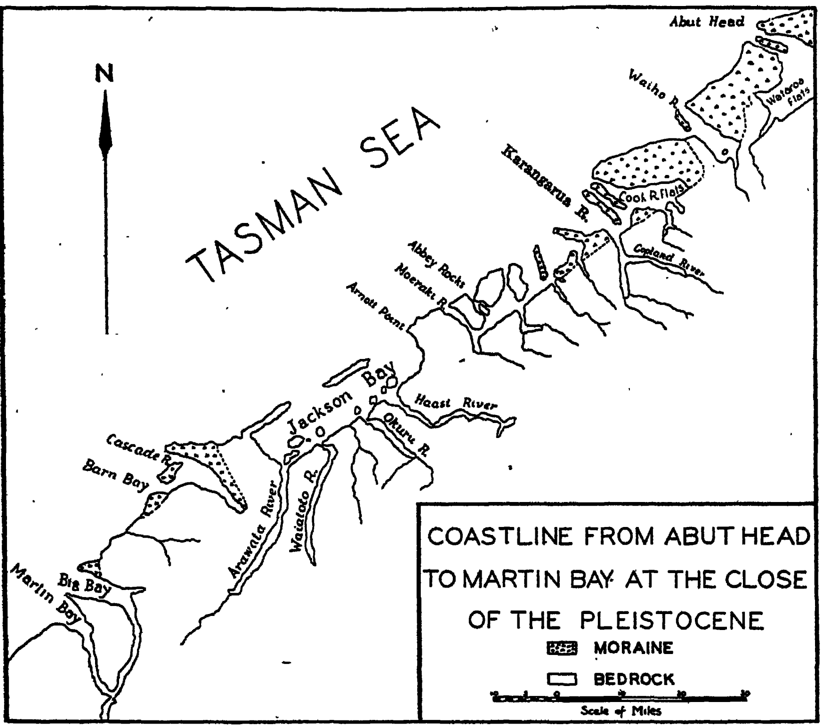
Chlamys sp. probably *zelandiae* (Gray).

Found in marine waters, but never in estuarine conditions of very decreased salinity; that is, less tolerant than the above.

Depth range: Low tide to 25 fathoms.

Te Whanga Lagoon, Chatham Island, receives little increment of fresh water streams and is under tidal influence; here both species of A, above, just manage to exist. With the greater inflow of water from the Hollyford River into Lake McKerrow, similarly influenced by tides, it is unlikely that these species could exist at the present time; certainly the *Chlamys* could not do so.

If the chief difference between the Southland fiords and the glaciated South Westland valleys is in the amount of post-glacial debris that has accumulated in them, then they have to be considered together when discussing their method of formation. Advocates of the glacial origin of fiords are, in Gregory's opinion (1913, p. 361–2), faced with the difficulty of explaining the absence of fiords on the West Coast in the Mount Cook area where the maximum development of the glaciers took place. Gregory (1913, p. 361) states that "the west coast near the chief glacial centre is straight and unbroken instead of being fiord indented." This straight and now almost mature coast is largely due to post-glacial alluviation having filled the indentations; and if the recent material were removed the coast would be indented as much as that of Fiordland. An attempt has been made to show the form of this coast shortly after the retreat of the ice by a text map, in which the sea is shown as extending into those areas where recent alluvium now extends below sea-level. As the floors of the main valleys do not usually rise far above sea-level and as the sides are only less steep than those of the fiords, little alluvium has accumulated above sea-level and the floors of the valleys almost represent the position previously occupied by the sea.



COASTLINE FROM ABUT HEAD TO MARTIN BAY AT THE CLOSE OF THE PLEISTOCENE

Independent evidence for fiord conditions during glaciation is provided by the fossiliferous, varved silts at Pug Creek, which is almost opposite the highest part of the Alps. These fine-bedded silts could not have been deposited in other than sheltered water and the

fossils they contain show that the water was, like that of the fiords, of normal salinity. It is almost certain that the lower part of Omoeroa Valley was then an arm of the sea.

It is likely that both the fiords and the glaciated valleys of South Westland were freed from ice at about the same time; consequently, the difference in amount of post-glacial alluviation is not due to the difference in time which has elapsed since the ice retreated from these areas but must depend upon other factors. The chief factors to be considered are:—

(a) The volume of the valleys below sea-level when freed from ice;

(b) The rate at which material was transported to these valleys. It is not possible directly to compare the volumes of the sea-filled fiords with that of the alluvium-filled Westland valleys; but although the depth may be somewhat less, the width of the valleys is about the same, so the volumes will be of the same order. There are, however, much greater differences in the quantities of material now being carried down by the rivers than there is in the volumes of the valleys in the two areas. For this there are two reasons; the first is the difference in the rocks being eroded and the second is the difference in relief. In western Southland, granite and other material, almost as resistant to erosion, form the mass of the rocks while in South Westland much less resistant schist forms the headward part of the valleys. The difference in relief is also considerable, for in South Westland the main rivers drain areas which rise to 7,000 or 8,000 feet, while in western Southland the maximum height is little over 6,000 feet. This height difference becomes more significant when we consider the area above timber line where erosion is much more rapid, this area must be ten times as large in South Westland as in western Southland.

Early Pleistocene Deposits.

Early Pleistocene beach deposits are confined to narrow, elevated beaches close to the coast. The most southern of these deposits extends from Sardine Terrace, just north of the Haast River, towards Arnott Point. Another area of these deposits is almost continuous from Abbey Rocks to the mouth of Paringa River. They are again represented at a greater elevation at Sandfly Creek and Cement Hill, both near Omoeroa River. The following relations indicate that the deposits are older than the greatest advance of the ice.

(a) The deposit at Sandfly Creek is overlain by morainic material.

(b) Elevated coastal benches are confined to non-glaciated areas (the problem of the "Coastal Plateau" in southern Fiordland is discussed earlier) and none were observed on any of the moraines, although this material is nearly as resistant to erosion as the Tertiary rocks in which the Pliocene benches are cut.

Both the Sardine Terrace deposit and that at Cement Hill have been worked for the gold contained in the lenses of magnetite interbedded with the sand and gravel, consequently, these deposits can now be easily examined. In both cases the material of the deposits is identical with present-day beach deposits, with the exception that some of the magnetite has been oxidised and cemented the surround-

ing sand. This process has so well cemented the sand grains that much of the gold cannot be freed until the black sand is roasted.

The Cement Hill deposit is situated about 400 feet above sea-level and about a mile east of the junction of Gibbs Creek and Omoeroa River. The surface of the deposit is level; and the concentrations of magnetite extend across this flat parallel to the present coastline, being bounded to the north-east by the valley of Gibbs Creek and to the south-west by the valley of Omoeroa River. The seaward-facing front of the hill slopes steeply into Gibbs Creek and on the opposite side the morainic material rises steeply from the edge of the flat. In line with this deposit, on the south side of the Omoeroa River is similar material, well exposed at the head of Sandfly Creek. There, marine sands are interbedded with silts and the whole is overlain by a considerable thickness of moraine. In spite of the fact that these deposits appear to be older than the associated morainic material, they are relatively close to the present shore line, and do not show the extreme weathering so characteristic of the Moutere Gravels in the type locality. Consequently, they may be younger than the Pliocene-Pleistocene orogeny postulated in the first part of this paper (Wellman and Willett, p. 305, 1942) as occurring after the deposition of the Moutere Gravels, and may have been formed immediately prior to or during the main advance of the ice.

Post-Glacial Deposits.

From the Mahitahi River north to Ross, sand and gravel beaches alternate with morainic bluffs. The morainic bluffs are connected by even, arcuate beaches. The coastal irregularities left on the retreat of the Pleistocene ice have been reduced partly by erosion of the seaward-sloping moraines by wave attack and partly by the infilling of intervening areas lying below sea-level on the retreat of the ice. The infilling of these areas has not been continuous and regular; and in the past it probably alternated with periods of erosion, as it does at the present day. Haast (1879) held that such a process was responsible for the infilling of the areas lying between the morainic ridges. The initial stage appears to have been the formation of a sand-bar well back from the present coast and separated from the moraine at the back by a depression that is at present occupied by a lagoon.

A series of sub-parallel crescent-shaped ridges composed of sand and gravel extend out from these lagoons to the present beach, and the deposits of magnetite and gold probably concentrated during periods of coastal advance and later buried under these ridges have been extensively worked for gold, first by hand and, later, at Gillespies and Okarito, by dredging. The process of heavy-mineral concentration is still continuing and a considerable advance of the sea is often accompanied by the deposition of several inches of black sand with a gold content ranging from nothing to several ounces per ton. The gold is probably derived partly from the moraines and partly from the material brought down by the rapid rivers. Concentration is probably more intense on the coastal beaches than in the rivers, for although payable gold has been worked on the coast as far south as Haast River, little payable gold has been found in the rivers south of Wataroa River.

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APPENDIX.

Dr. C. A. Cotton has drawn the authors' attention to an omission, in Part 1 of this paper, of reference to R. Speight (1910) in which the alpine drainage is considered to have developed upon the surface of an arched alpine peneplain.

SPEIGHT, R., COCKAYNE, L., and LAING, R. M., 1910. The Mount Arrowsmith District; a Study in Physiography and Plant Ecology. *Trans. N.Z. Inst.*, vol. 43, pp. 315–378.

Notoscolex equestris, an Earthworm from the Poor Knights Islands.*

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[*Read before the Otago Branch, June 9, 1942; received by the Editor, June 24, 1942; issued separately, December, 1942.*]

During November, 1940, I received from Mr. R. G. Turbott, of the Auckland Memorial Museum, two phials containing earthworms—one phial from the Chatham Island Group, the other from the Poor Knights Group, which is situated off the north-east coast of the North Island of New Zealand.

The smaller of the two phials contained those collected by him in leaf mould and loose soil on the South-east Island of the Chatham Group. In it are four earthworms. The two largest belong to the species *Rhohodrilus huttoni* (Benham) †—formerly placed in the genus *Microscolex,* this species was removed by Michaelsen (1907, p. 142), as it possesses a gizzard, which is absent in the former genus. The two other worms are much smaller, and are some species of the introduced genus *Allolobophora,* but owing to the state of immaturity and to the poor condition of preservation, it is impossible to be more precise.

It is with the contents of the larger phial from the Poor Knights that the present article is concerned. This phial contained two large earthworms collected in leaf mould by Majors G. A. Buddle and R. A. Wilson, on Tawhiti Rahi, the northern island of the group. They are excellently preserved in strong alcohol, and are now in the Auckland Museum.

Notoscolex equestris n.sp. (Pl. 17.)

External Features: The length of the larger of the two, which forms the subject of this article, is 210 mm., with about 150 segments, all of which are practically of the same length. The diameter is almost uniform throughout the length, the worm being thus almost cylindrical, scarcely tapered posteriorly; for at a distance of 20 mm. from the anterior end its diameter is 14 mm., and at the same distance from the posterior extremity it is 10 mm. The greatest diameter at a short distance in front of the clitellum is 16 mm.

The pigmentation, or rather the plan of pigmentation, is very striking. A broad band of dark chocolate brown crosses the dorsum of each segment, and is separated from its neighbours by a narrower, pale cream-coloured intersegmental band. The appearance is thus somewhat zebriform. Such a scheme of colouration is unusual, but not unknown in earthworms from other parts of the world, and

* Equestris—according to Smith's Latin-English Dictionary, "belonging to the order of Knights."

† Benham, 1900. On some Earthworms from the Islands around New Zealand. *Trans. N.Z. Inst.*, vol. 33, p. 140.

belonging to different genera—the European "Brandling" *Eisenia foetida* has purplish-brown segmental bands with paler intersegmental bands, and Pheretima, for instance, various species of which are found in the Melanesian Islands, as I described many years ago. (Benham 1895–1896.) But in those species the position of the band is reversed —it is the dark band that is intersegmental.

This is the first case of such ornamental colouration to be recorded from this country. It resembles the pattern on the abdomen of certain large species of Deinacrida, amongst the Orthopterous insects.

This colour scheme is continued forwards to the fourth segment, though in front of the clitellum the intersegmental pale bands get narrower till they cease. In these four segments the dark pigment is continued round to the ventral surface, where the light intersegmental band is, however, visible. Except in these anterior segments and in the region of the clitellum the ventral surface is a pale buff or cream colour, the dark pigment ceasing at about the lateral line as indicated by the chaeta (*c*).

In addition to this striking colouration, another noticeable character is afforded by the small white circular spots or papillae on the dark bands on the post-clitellar segments. These mark the position of the chaetae, "*c*" and "*d*," that is the latero-dorsal and the dorsal couples. (Pl. 17, Figs. 1 and 2.)

There are two such spots on each side of each segment; the uppermost spot is not in a straight line along the body, but occurs at different levels in successive segments; that is, in no two successive segments are the dorsal chaetae at the same level, at the same distance from the mid-dorsal line. This irregularity in the position of the chaetae is unusual, but in some species of *Notoscolex* described by Fletcher from Australia, this aberration from the linear arrangement occurs. With these few exceptions, in all the hundreds of species described, these chaetae form continuous straight lines. These wandering spots indicate, as I say, the position of the dorsal chaetae: the other spot, nearer the edge of the dark band, is likewise somewhat iregular, but none wander so far from the normal position as do these containing the dorsal chaetae.

The occurrence of white spots around the chaetae is not unknown; for instance, I described this condition for a little worm named *Plagiochaeta punctata* (Benham, 1892, p. 294), in which, however, there are many chaetae in a segment instead of the more usual eight.

In the present worm six of the eight chaetae are visible from the ventral surface, and are practically equidistant (apart from the divergences of "*c*"). Using the ordinary symbols, and starting from the most ventral chaetae, *a–a* equals *a–b* equals *b–c,* though the position of the last varies slightly. Measured on the stretched body wall, the distances are:—*a–a* 4 mm., *a–b* 3 mm., *b–c* 4 mm. (usually), *c–d* 5 mm. at the least as in segment XXV, but may rise to 6, 7, 8, or even 9 mm. in succeeding segments.

One small detail may be mentioned, that, owing to the thickness of the body-wall and to its contracted condition, the ventral and ventro-lateral chaetae "*a*" and "*b*" are not visible anteriorly to segment X.

The above may seem a lot of talk about a small detail, but the arrangement is so unusual that it must be excused.

The *Prostomium* is epilobic.

I was unable to detect the dorsal pores owing to the strongly contracted state of the body.

The *Clitellum* occupies segments XIV, XV, XVI, and XVII. It is a complete girdle of dark brown lacking the pale intersegmental bands, and the dark tint is only interrupted ventrally in XVII.

Genital Markings: On the ventral surface of each of the two segments XVII and XIX is a pale-tinted, transversely elongated, sucker-like structure with a rounded raised margin and a slightly depressed centre. Its length is about equal to one-third of the diameter of the worm, extending nearly as far as chaeta "*b*" on each side.

There is nothing unusual about this feature. It is almost exactly like the "genital markings" figured, for instance, for *Megascolex tripartitus* by Stephenson (1930, p. 420), and somewhat similar markings occur in various genera.

Genital Apertures: The male pores are in XVIII, in a similar transverse furrow though much narrower antero-posteriorly. The actual pores are in rather deep depressions close to the outer ends of this furrow, in line with chaeta "*a*." The oviducal pores are in the usual segment XIV, close together in a very short transverse depression in the median line between the chaetae "*a*" and "*a*." (Pl. 17, Fig. 3.)

I am unable to detect the spermathecal pores, though at the anterior margin of VII there is apparently a transverse impress in line with "*a*" which is probably one pore. But there are, as dissection shows, three pairs of spermathecae in VII, VIII and IX, hence their pores will be at the anterior margin of these segments.

Internal Anatomy: The worm is micronephric, the minute tufts of tubules forming a dense velvety lining to the body wall, extending even to the dorsum. These micronephridia are continued to the hinder end of the body. There are no meganephridia.

Reproductive System: The testes and ciliated funnels are in the usual segments X and XI. They are concealed, however, by a horizontal membrane extending from septum to septum, reminding one of the median sperm sacs in *Lumbricus* and other genera. The two pairs of sperm sacs lie in IX and XII; ovate to subspherical and smooth walled.

The prostate in XVIII is rather long, narrow and tongue-shaped, with a rough surface, the margins being somewhat indented at intervals. It has a short muscular duct. The organ extends through four segments in the specimen dissected, reaching to the hinder septum of XXII. (Fig. 4.)

I am unable to trace the sperm duct owing to the hard condition of the body wall, so am unable to locate its actual connection with the prostate duct (which, according to Gates, seems to have some importance).

The ovary and oviduct are in the normal segments, XIII and XIV respectively.

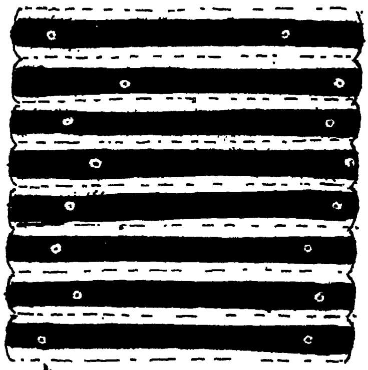

Fig 1

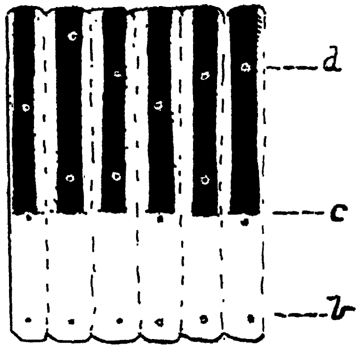

Fig 2

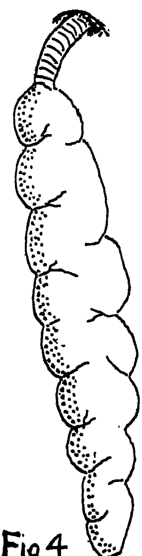

Fig 4

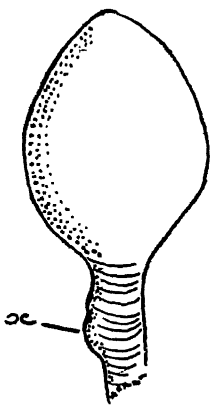

Fig 5

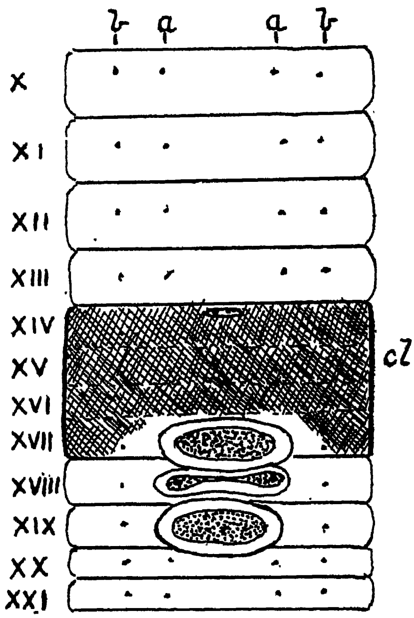

Fig 3

FIG. 1—Dorsal view of a portion of the mid-body, showing the colour pattern and the white chaetal spots, and the irregularity of the dorsal chaetae (× 2).

FIG. 2—Side view of a more posterior portion (× 2).

FIG. 3—Ventral view of the region of the clitellum and genital markings, etc. (× 2) *a*, *b*, *c*, *d*, the four chaetae.

FIG. 4—A prostate (× 4).

FIG. 5—A spermatheca (× 4). *x* The slight excrescences on the duct.

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There are three pairs of *spermathecae,* progressively increasing in size, in VII, VIII and IX, opening near the anterior boundary of their segments. The last organ lay transversely, and was hidden by the first sperm sac, so that it was at first overlooked. Each spermatheca is an ovate sac without recognisable diverticulum, and with a comparatively long duct, that of the first one being as long as the sac itself. (Fig. 5.)

Removed from the body and examined microscopically (but not in section), the duct presents two low, rounded excrescences on one side near the proximal (extal) end. Whether these play the part of a diverticulum I cannot say. But such excrescences are scarcely worthy of being termed "diverticula," as Stephenson apparently so calls them, for in *Megascolides annandalei* (now placed by Gates in his genus *Barogaster*) and in *B. prashadi* Gates, and in one or two other species these "diverticula" are described as " flattened " and "adherent to the duct."

On the floor of the body in XVII and XIX, corresponding to the external structures, are glandular thickenings.

Many of the anterior *septa* are thickened, namely 6/7 to 12/13, and those in the latter part of the series are especially thick.

Alimentary Tract: The gizzard is in VI, its wall is not very hard. The anterior and posterior septa of this segment are quite distinct and have not suffered a backward shift as in so many earthworms.

The oesophagus is thick walled, cream coloured and cylindrical. There are no special " glands " or enlargements. The lining is, however, thrown into a number of longitudinal folds with rough edges.

The intestine commences in XVII. It is thin walled and sacculated, but the hinder region in the last ten segments is, as in *Megascolides napierensis* Benham (1941), a straight, thick-walled " rectum." Neither Beddard nor Stephenson in their Monographs of the Oligochaeta mention the existence of a " rectum," or any modification in these hinder segments. In a general way zoologists do not seem to have dissected the posterior region, as all the really diagnostic characters are to be found in the anterior segments.

There is no typhlosole, unless the slight ridge produced by the attachment of the dorsal blood-trunk is to be so designated. But the typhlosole of such a genus as *Lumbricus* has a definite structure and function which has not been allotted to such a feeble ridge as is present here and in many other genera, where " no typhlosole " is recorded.

Of the vascular system I can only record that the dorsal trunk is single, and that enlarged " lateral hearts " exist in X, XI, XII and XIII.

DISCUSSION.

I have recently (1941, p. 30) referred to the small differences which separate the two genera *Megascolides* McCoy and *Notoscolex* Fletcher, the only fundamental difference being the microscopic structure of the prostate.

So long ago as 1892, Beddard (p. 130) wrote: "The discrimination of the genera of the Cryptodrilidae is unfortunately the most difficult part of the classification of the Oligochaeta." And so it is to-day, 50 years later, as the number of species has been studied anatomically.

As an illustration of this uncertainty, mention may be made of my genus *Tokea* (1905). In 1907 Michaelsen (p. 161) regarded this genus as really included in *Megascolides*. In 1916 (according to Stephenson (1923, p. 193, and 1930, p. 835), for I have not access to the original paper, Michaelsen includes it in the genus *Notoscolex* on the ground of the microscopic structure of the prostate. Again, in 1910, Michaelsen (p. 36), in discussing the geographical distribution of these and related genera, refers repeatedly to the occurrence of *Megascolides* in New Zealand and Ceylon, but in 1916 comes to the conclusion that New Zealand earthworms formerly attributed to *Megascolides* must be removed from that genus to *Notoscolex*. Consequently New Zealand must be excluded from the geographical distribution of *Megascolides*. And so my *Tokea* has been shifted about, first as a subgenus of *Megascolides* in 1907 (p. 161), and then to *Notoscolex* in 1916. Now when our greatest authority on the Oligochaeta (unfortunately deceased) is so uncertain as to the limitation of the two genera, refers repeatedly to the occurrence, it is not surprising that Stephenson (who is likewise defunct), and who was, as his Monograph reveals, the next authority on the group, but who had followed Michaelsen, should have presented two opinions as to *Tokea*, for in 1930, p. 658, he refers to the edibility of "*Tokea (Megascolides)*," while on p. 837 he wrote: "*Tokea* must now go into *Notoscolex*." Confusion worse confounded!

As I have mentioned above, the fundamental difference between the two genera lies in the microscopic structure of the prostate, but many species have been described attributable to one or other of these two genera, in which, however, the internal structure of this organ is unknown; and Stephenson (1923, p. 194) remarks: "But to reduce the necessity of resorting to this procedure, it may be assumed that the flattened, tongue-shaped gland, especially if the boundaries have any trace of lobing, will have branched ducts; while glands which are definitely cylindrical in shape will quite possibly have a simple duct." This seems rather like guesswork, and can only be employed if the author of a species has described or figured sufficiently carefully the form and appearance of the prostate, and unfortunately this has not always been the case. But this illustrates the awful state of uncertainty that surrounds any attempt to distinguish these and some allied genera.

I have alluded to Stephenson's views in my former paper (p. 31). I have allotted the present worm to the genus *Notoscolex* rather than to *Megascolex* or to *Tokea* on the following grounds: There are only three pairs of spermathecae, and the prostate is tongue-shaped with lateral incisions and lobings along its margins, which suggest a branching system of canals. It differs in this respect from *Megascolides*, while from *Tokea* it differs in (a) the external and therefore probably the structure of the prostate; (b) the absence of recognisable diverticula on the spermathecal duct; (c) the gizzard is in VI instead of V; (d) absence of meganephridia in the posterior segments.

REPRESENTATIVES OF THE FAMILY CRYPTODRILIDAE IN NEW ZEALAND.

This family, which is characteristically Australian, is represented in the Dominion by the following species:—

1. Schmarda's "*Hypogaeon orthostichon*" (1861) placed by Beddard in *Megascolides* and by Michaelsen in *Notoscolex* (1916).

2 and 3. Ude's *Notoscolex reptans,* and *N. unipapillatus* transferred to *Megascolides* by Michaelsen in 1916.

4 to 11. Benham's *Tokea* with 8 species, transferred finally to *Notoscolex* in 1916 by Michaelsen, or perhaps a subgenus thereof.

12. *Megascolides napierensis* Benham, 1941.

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The Octopodous Mollusca of New Zealand.

I.—THE MIDGET OCTOPUS OF THE COASTAL WATERS.

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[*Read before the Otago Branch, June 9, 1942; received by the Editor, June 24, 1942; issued separately, December, 1942.*]

THE following species of *Octopus* have been recorded from the coastal waters around New Zealand:—

1. *O. maorum* Hutton, 1880.
2. *O. communis* Park, 1883.
3. *O. australis* Hoyle, 1886.
4. *Pinnoctopus cordiformis* Quoy and Gaimard, 1833.

The diagnoses of these species, with the exception of *O. australis*, are given in Suter's *Manual of Mollusca*, 1913, and are copied from the original accounts. Suter added nothing to our knowledge of this group from his own observations, and these earlier diagnoses are very superficial and insufficient to enable one to be certain of the animals to which they respectively refer.

The more recent method of distinguishing species of this enormous genus, so widely distributed in all oceans, is that of Robson (1929), in his Monograph, published by the British Museum and covering about 100 species.

In the determination and description of species at the present time it is no longer sufficient to give in general terms the shape and size of the body, its colour and ornamentation and the relative length of the arms, etc., as was done by the earlier zoologists. It is now necessary, if we are to follow Robson, as we must, to make about a dozen accurate measurements of each individual and reduce these to a percentage of the length of some standard, such as the length of the mantle—quite a laborious and tedious proceeding involving some twenty mathematical calculations for each individual: multiply this by 23, and it is seen that one is justified by using the word "laborious." Then with about two dozen individuals one has to obtain the range and the average of each of these measured items, or "indices" (as Robson terms them) in order that one may compare them with those for allied species as detailed in his Monograph. I give later in this article the facts in tabular form.

With regard to New Zealand species enumerated above, Robson (1928) gives a detailed account of the external and some internal features of two male individuals of *O. maorum* in that collection, and in his Monograph suggests that *O. communis* is probably a synonym of that species which is the type of a new sub-genus *Macroctopus*. Unfortunately, the type of Park's species was lost when the Nelson Museum, in which it was housed, was destroyed by fire.

As to "*Pinnoctopus*," Robson (1929, p. 185) suggests, since no one has described it since Quoy and Gaimard, that it was probably a specimen of *O. maorum* "having adventitious lateral folds of the skin."

These New Zealand species vary in size from the "Giant" (*O. maorum*) whose total length may be as much as 5 feet 8 inches and its body alone about 10 inches (Robson) down to the "Midget" (*O. australis*) whose body does not exceed an inch and a half in length, and its total length a mere three to four inches.

In this present article I concern myself with this well defined, small littoral octopod originally described by Hoyle in the *Challenger Reports* from Port Jackson, N.S.W., namely, *Octopus australis*.

In his Monograph, Robson, in a footnote on p. 145, transfers this species to a new genus *Joubinia*, which he characterises (p. 187) in the following terms:—

"Octopods with the web equally developed in all its sectors and but little continued up the arms. The adlateral tooth of the radula is bicuspid (?). The penis has a second diverticle and a long primary diverticle (like *Enteroctopus*). The ligule of the hectocotylus resembles that of *Bathypolypus*, having markedly inrolled sides and wide cheeks."

He emphasises the last two points as being different from those in the genus *Octopus, sensu latu*. But in 1938 Adam points out that this title *Joubinia* has been used by Bürger for another animal and suggests in its place the name *Robsonella* for the octopod.

Hence the synonymy of this small creature is:—

Genus ROBSONELLA Adam, 1938.
Joubinia Robson, 1929.

Robsonella australis (Hoyle, 1885).

Octopus australis Hoyle.
Polypus campbelli Smith, 1902.
Polypus australis Massy, 1916, and Berry, 1918.

Of this small species I have examined 23 individuals, of which 5 are males and 16 females, some of which I have dissected, so that I am able to add something to the facts recorded by previous zoologists, none of whom appear to have studied the internal anatomy.*

I am able thus to extend our knowledge, for during my curatorship of the Otago University Museum I preserved all animals that were brought in to me, whether common or rare, known or unknown specifically, in the hope and expectation that at some future time zoologists may wish to study the groups to which they belong.

In my ignorance I supposed that these little octopods, as well as some other rather larger ones, were the young of the large *O. maorum* and they were registered under that name, for I had not time always to examine the animals as they came in (for I was also Professor of Biology), and all one could do was to record locality and donor.

But one day a small specimen about two inches in length was received accompanied by the eggs laid by her. This opened my eyes to the fact that these small littoral octopods might be mature and consequently belonged to a species distinct from *O. maorum*.

Distribution of the species as recorded by Robson:—Port Jackson, 5–15 fathoms; Hoyle. Spirits Bay, North Island, New Zealand,

* After completing the manuscript of this account seven more specimens of the species were obtained in or near the entrance to the Otago Harbour.

11–20 fathoms; Massy. Gray's Beach, New South Wales; Brazier. Off Gabo Island, Victoria; Berry.

My own collection includes additional localities off the coasts of New Zealand:—Hawke's Bay.* Portland Island, off the Mahia Peninsula, East Coast, North Island. Tasman Bay, 10–30 fathoms, Nelson. Foveaux Strait, 17 fathoms. Otago Harbour. Stewart Island; shore.

It is thus distributed along the whole of our coasts from the extreme north, Spirits Bay, to the extreme south, Stewart Island; on both the East and West Coasts.

The number of individuals and the sex:—

Reference Letter.	Museum Register or *ad hoc* number.	Number of Individuals.	Sex.	Locality.
A	A.'28.24	6	3 m. 3 f.	Portobello, Otago H.
B	1931	3	3 f.†	Otago Harbour.
C	22	2	1 m. 1 f.†	Stewart Island.
D	A.'15.34	1	1 f. with eggs.	Oyster beds, Foveaux Strait.
E	A.'29.111	4	1 m. 3 f.	Oyster Beds, Foveaux Strait.
F	(——)	3	3 f.†	Portland Island.
G	Coll. G. M. Thomson	2	2 f.	Tasman Bay, between Nelson and Stephen Is, 10–20 fathoms.
H	(——)	2	2 f.	Hawkes Bay.

As these are at the time of writing still stored in the Museum, these reference letters and registration numbers will allow any further zoologist to compare them and to recognize the individuals referred to in this account. I have also deposited with the Director the results of the measurements of the specimens.

General Account of External Features. (Fig. 1.)

Robsonella australis is a littoral or shallow-water species of small size, measuring usually about one inch in length and three-quarters of an inch in breadth. Details of actual measurements are given later. (See p. 235.) The nearly spherical body is on its dorsal surface beset with closely-arranged, small, rounded papillae, which may be continued over the head on to the dorsal arms and web (or "umbrella" of some authors). The colour is a pale to darker brown, uniform in tone and is usually paler ventrally, where the skin is smooth. There are no special markings, though in some of the individuals there are a few darker spots along the dorsal arms.

The eyes are somewhat prominent, but this seems to vary according to the condition of preservation. In most cases a small and inconspicuous supra-ocular cirrus is evident, though it is absent in others. The arms are approximately of equal length, though the two dorsals are slightly shorter and the dorso-laterals slightly longer, when measured in millimeters. They are 2½ to 3 times as long as the body.

In none of the 23 specimens are any of the suckers suddenly enlarged as Smith describes and figures for *O. campbelli* (p. 202,

* I owe thanks to Dr Oliver, Director of the Dominion Museum, for allowing me to examine these.

† Some of the above are very small, viz. those of B; one f. of C; two of E. These are about ½ inch or less in diameter.

pl. XXIV, figs. 9, 11). As no later author has referred to these enlarged suckers, one must regard them as being an abnormality, and not, as Smith suggested, an indication of the male sex. This they certainly are not. There is no difference in size of body, nor in other external features between male and female: other than the presence of the " hectocotylus " in the male.

The extent of the " web " or " umbrella " between the arms is approximately equal in all the inter-brachial spaces, being about one quarter to one fifth the length of the arm, though in most instances that between the pair of ventral arms is shorter than the rest.

The mantle aperture is wide, extending from the level of the eye on each side.*

The funnel or " siphon " extends usually about halfway along the ventral side of this sector of the web, though its length is somewhat variable, according to state of contraction.

An important organ amongst the external features is the Hectocotylus in the male. This spoon-shaped structure is a modification of the extremity of the third arm of the right side. In this genus this has a very characteristic form (fig. 5). The short, oval, spoon-shaped " ligula " with well-rounded, inturned and thick lateral lips overhanging the groove, which is deep and broad; there are no transverse laminae or ridges across the floor, such as occur in some species of Octopus. Projecting into this space is the " calamus," short and pointed, indeed tongue-shaped and traversed by a groove in continuation with the seminal groove along the side of the arm, formed by the narrow extension of the web of the arm.

The hectocotylus in the present series agrees more closely with that figured for *campbelli* (Robson, p. 190) than with his figure for *australis* on p. 145, in which the lips of the ligule are relatively much thicker and apparently overlapping the groove more than in those examined by me. But this seems to be a result of greater contraction.

VARIATIONS.

The above is a general account which will enable anyone to recognise this little octopod, but some remarks must be made as to any variation from these statements.

Shape of Body.

Although many of our specimens are globular, others tend to be oval; in some, the greatest diameter of the body is near the anterior end, in others near the hinder end. In some the hinder end is more or less pointed. (Fig. 3.) For example, in the two specimens from Tasman Bay (G) one is " bursiform " or globular, the other a narrower oval and somewhat pointed posteriorly.†

In two individuals from Stewart Island a similar variation occurs; and I have found like differences in shape in several other localities. So that Robson is justified in his remark (p. 25): " It is evident that the shape of the mantle (i.e. " body ") can only be used

* By what is evidently a slip of the pen, Robson in his description of this species, on p. 144, writes that "the mantle aperture is narrow (C)," but on p. 26 he defines (C) as "wide," and Hoyle (p. 88) says it extends "nearly half-way round the body": and so it is shown in Smith's figure 8, pl. XXIV.

† The outlines were taken by running a scalpel round the body, incising the underlying card, and then pencilling this mark.

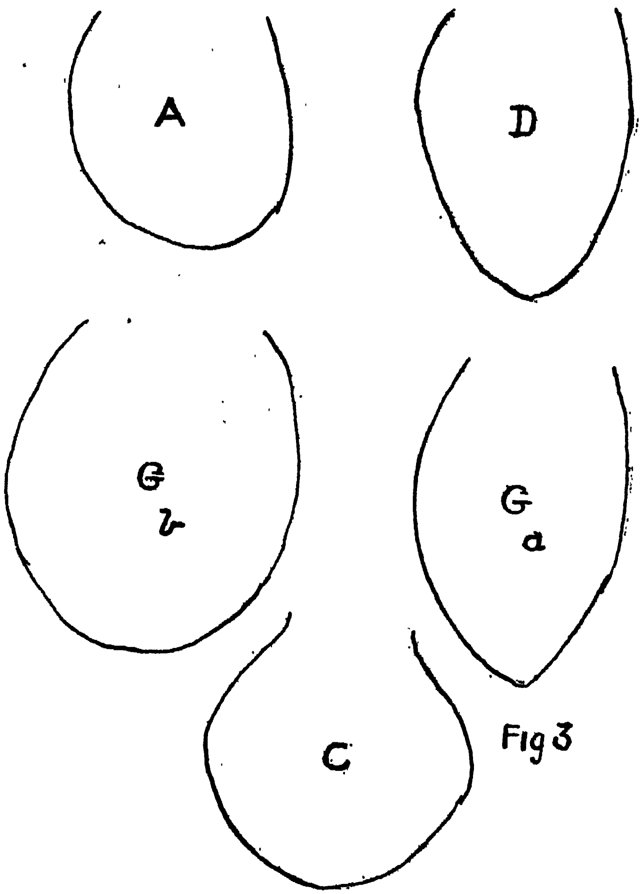

FIG. 3.

Outlines of five individuals to show variations of form of body (n.s.). The letters refer to the list of specimens on p. 228.

A—The more usual or typical form.

D—The female which laid the eggs.

for the discrimination of species with very great caution." The colour likewise is somewhat variable, depending to some degree on the liquid used for preservation; thus in those preserved in formaline the brown has a pinkish tint, which is quite absent from those in alcohol; formaline is preferable to alcohol as a preservative for these octopods, especially for the study of the internal anatomy. I note that in those from Portland Island the basic colour is "marbled purplish and pale brown."

In some individuals there are in addition to the uniform round papillae of the dorsum a few somewhat longer conical tubercles scattered amongst them: as in those from Portland Island and some of those from Portobello (Otago Harbour).

In Hoyle's type there is figured a pair of ventro-lateral ridges on the ventral side of the mantle (1856, Fig. 5). No other author has

FIG. 1.

Robsonella australis Hoyle. Photograph of E. A. Smith's figure of the animal in the "Southern Cross Expedition." The hectocotylised arm is seen on the right side. (Nat. size.)

FIG. 2.

Oyster shell with egg masses of the same species ($\frac{3}{4}$ n.s.). Photographed by G. D. Anderson.

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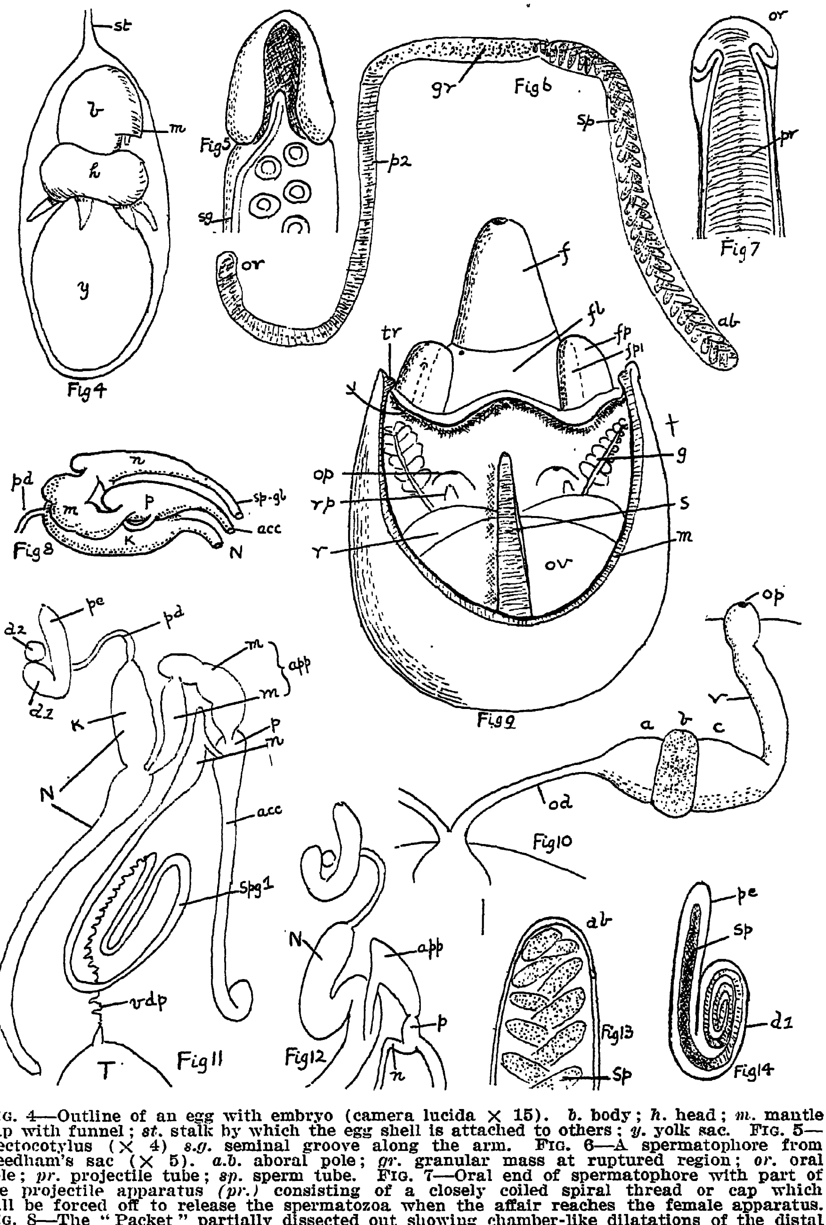

FIG. 4—Outline of an egg with embryo (camera lucida × 15). *b.* body; *h.* head; *m.* mantle flap with funnel; *st.* stalk by which the egg shell is attached to others; *y.* yolk sac. FIG. 5—Hectocotylus (× 4) *s.g.* seminal groove along the arm. FIG. 6—A spermatophore from Needham's sac (× 5). *a.b.* aboral pole; *gr.* granular mass at ruptured region; *or.* oral pole; *pr.* projectile tube; *sp.* sperm tube. FIG. 7—Oral end of spermatophore with part of the projectile apparatus (*pr.*) consisting of a closely coiled spiral thread or cap which will be forced off to release the spermatozoa when the affair reaches the female apparatus. FIG. 8—The "Packet" partially dissected out showing chamber-like dilatations of the distal regions of the ducts (k, m, n, p). FIG. 9—The interior of the mantle chamber seen by removal of the mantle flap; *f.* funnel; *fl.* funnel lock, the index line should reach the trans. ridge; *fp.* adsiphonal pouch; *fp.1.* thickened region of its wall; *g.* gill; *m.* cut edge of mantle flap; *o.p.* oviducal pore; *ov.* ovarian sac; *r.* renal sac; *rp.* renal pore; *s.* septum; *tr.* thickened ridge on mantle edge. FIG 10—Female reproductive apparatus (× 4). *a.b.* the two chambers of the spermoviducal gland; *c.* enlarged commencement of the vagina; *od.* oviduct; *op.* external pore; *ov.* ovarian sac; *v.* vagina. FIG. 11—Male apparatus of a mature individual, unravelled and displayed (enlarged); *acc.* accessory gland; *app.* appendix; *d.1.* chief diverticulum; *d.2.* the characteristic second diverticle; *N.* Needham's sac; *k.* anterior chamber of Needham's sac; *m.m.* parts of the appendix; *n.* enlargement of sph.; *p.* distal enlargement of accessory gland; *pe.* penis; *p.d.* penial duct (or distal vas deferens); *spg.* spermatophoral gland; *T.* testicular sac; *vdp.* proximal vas deferens (or vas efferens). FIG. 12—The male apparatus of an immature individual (× 6). The appendix is much simpler. FIG. 13—The aboral end of a spermatophore (much enlarged). sp. masses of spermatozoa arranged in a spiral. FIG. 14—The penis and chief diverticulum opened to show the contained spermatophore of a mature individual (much enlarged).

observed these, and even Hoyle suggests "possibly it is due to differing modes of preservation or to varying conditions of contraction." In none of the 23 individuals in my collection is there any trace of a ridge. But in some there is a shallow, more or less evident furrow in the median line of the ventral surface, which is due to the degree of contraction of the septal muscle which is attached to the inner surface of the mantle forming the septum between the right and left pallial chambers.

MANTLE CHAMBER. (Fig. 9.)

The funnel of most species of Octopus presents on its dorsal lining a W-shaped glandular ridge, known as the "funnel organ." I have seen no clear evidence of its form in this species. The adjacent "adsiphonal pouches," one on each side of the base of the funnel, open posteriorly into the pallial chamber behind the "funnel lock."

I have not been able to find a clear statement as to the function of these pouches; Naef is not very expressive in the matter. Do they not assist the flaps of the "lock" in closing the mantle aperture during respiration or locomotion? The compression of the wall of the pallial chamber forces the water forwards during locomotion; it will therefore enter the pouches and distend them, and the flaps of the "lock," which are actually the produced walls of the pouches, will be forced against the thickened edge of the mantle, and thus close the exit, allowing the water to escape only through the funnel.

The "funnel lock" consists of a pair of semicircular flaps separated by a slight notch in the middle line, but the thickened edge of these flaps is continuous over this notch.

The gill contains 6 or 7 or 8 lamellae.

The pallial septum, which separates the mantle cavity into right and left chambers, is perforated by an interpallial aperture, which in most instances is extensive, that is, it is as long as that part of the septum in front of it, or even longer. But in one of the individuals from Portobello (B) it is very small, quite far back near the posterior end of the septum.

Into the mantle chamber the genital and excretory ducts open. In the female the genital pore is paired as in all Octopods; so is the excretory pore. In this species the female pore is deep down in the chamber at the base of the gill, outside of and dorsal to the renal aperture. Whereas in the *Octopus vulgaris* and some other species this genital pore lies far forwards, alongside the anus.

INTERNAL ANATOMY.

Little appears to be known of the internal organs such as the alimentary tract and the reproductive apparatus, either for this species or for the genus itself. I have dissected three or four specimens in spite of the small size.

The alimentary system does not present any particularly diagnostic modifications on that of the well-known *O. vulgaris*. But the reproductive system both of the male and the female differs more or less extensively from those that are figured in such literature as I have been able to consult, viz., Marchand and Robson and Naef. However, I have been able to study Marchand's classic article on the male system (1907) and will follow his nomenclature.

The Female Apparatus. (Fig. 10.)

From the ovary or, more correctly, the "ovarian sac" at the posterior end of the body, the two slender oviducts arise from a short, wide, thin-walled, common "antrum" lying near the anterior limit of this ovarian sac. In one individual the ovarian sac occupies the greater part of the visceral cavity, extending from the posterior wall forwards nearly to the oviducal pore, from which it is separated by a portion of the renal sac; further, it extends from the mid-line to the lateral wall of the body. The oviduct passes obliquely forwards and outwards to a subspherical swelling, the "oviducal gland," or as Robson terms it (1929), the "spermoviducal gland," for he quotes (p. 138) an observation made by Racovitza in 1894 that separmatozoa were found therein. The "spermoviducal" gland consists in this species of two chambers in sequence, (a) a thick-walled, pale-coloured hemispherical chamber receiving the oviduct, and (b) a thin, translucent-walled chamber appearing dark owing to the character of its contents. This opens by a communication near the posterior end of the junction into a hemispherical, thick-walled, pale-coloured sac, (c) which leads into the long tubular vagina; this turns abruptly forwards to reach the oviducal pore lying close to the base of the gill, immediately anterior to the renal papilla.

So far as literature enables me to form a judgment, the vagina is a good deal more massive than in most species.

The Eggs.

By a fortunate chance the female from Foveaux Strait (specimen D) was accompanied by her eggs, captured in the same haul; they were deposited on the inner surface of the flat shell of an oyster. (Fig. 2.) The eggs are laid in groups of bunches, each bunch being independently attached to the shell by an axial thread to which the individual eggs are in their turn connected. About two dozen such bunches lie in this shell; each of which measures about 15 mm. in length, though larger bunches are also present; such a bunch contains about 60–70 eggs.

Each egg measures 2·5 mm. in length by 1 mm. in width; it is a much elongated oval, attached to the axial thread by a short stalk. Mounted in glycerine and studied after the temporary shrinking of the envelope has resumed its normal condition, it was drawn under camera lucida with a Zeiss number 2 objective and ocular 1. The figure therefore was 30 times natural size, but it is here reduced to half this. (Fig. 4.) The embryo had developed till the body, head and arms are differentiated. I was unable to make out the eye with certainty, as the rounded bulge seems almost equally prominent on each side, or rather on the dorsal and the ventral aspect as the body lies.

I have the eggs of another species which attain a greater size than this.

The Male Apparatus. (Fig. 11.)

The dissection of a mature individual from Stewart Island (C) exhibited the apparatus in its usual complexity, though in some respects it is more complicated than that normally described. The penis, which is 10 mm. in length, has the characters which Robson

found to be diagnostic of his genus *Joubinia,* that is *Robsonella* of Adam; it has in addition to the " chief " diverticulum, which is the upturned portion of the J-shaped structure, a small globular accessory diverticulum.* From the bottom of the loop formed between the penis and its diverticulum the " penial duct " or extreme anterior or " distal " portion of the " vas deferens " arises; this after a short course plunges into the anterior of a conspicuous oviform mass, about 7 mm. in height, which lies to the left of the penis. This is the " packet " of Marchand and contains or is formed by a series of chambers and tubes closely wrapped together; each is surrounded by its layer of connective tissue, and the whole bound by connective tissue. (Fig. 8). It will be appreciated by fellow anatomists that the unravelling of this small complex was a tedious and time-taking job. Oh! happy naturalists! whose concern is with such animals as Lepidoptera, or fishes or gastropod shells, where it is sufficient to study externals, either the colour pattern of the moth, or the number of scales and fin rays of the fish in order to ascertain the species.

This is not meant as a disparagement of such naturalists. Far from it; we recognise that their work has in the past as in the present been of immense service to the anatomist. The work of those enthusiasts laid the foundation for much of our knowledge to-day and is still necessary.

We anatomists have to take cognisance of the internal structure, which involves time and labour; but it is likewise an exciting business, tracing out these hidden organs, not knowing what the successive results may show. It is like exploring in some unknown country. And this particular job, requiring even more patience than the study of the anatomy of an earthworm, in that the connective tissue had to be carefully picked away, bit by bit so as to avoid injury to any one of the concealed organs; I made sketches of the outcome of each successive exposure of unravelling and displacement of the parts so as to find the relation of each to the other. The result is shown in the figure 11, which is somewhat simplified and rearranged.

It will be convenient to follow Marchand's plan of tracing the " vas deferens " from the testis. This organ lies as usual in the Octopods at the posterior apex of the body, enclosed, of course, in the " testicular sac." From this arises the " proximal vas deferens " (or " vas efferens " of earlier writers). This passes forwards as a delicate, much undulating canal amongst the coils of a wider tube, the " spermatophoral gland " (or as it was formerly called, the " seminal vesicle "). Into this long, coiling, glandular tube the " proximal vas deferens " enters.

This " spermatophoral gland " makes a long, double U-shaped course extending from the testis forwards. Its anterior, ultimate limb bends abruptly towards the animal's right side (it is displaced in the figure for convenience), and here the character of its wall changes, becoming a thin-walled, transversely disposed enlargement or " saccule " as I term it (*n*). From the wall of this " saccule "

* In a mature individual dissected later this secondary diverticulum is lacking, and the primary is very long, almost the length of the penis. Its rounded tip occupies the position of this secondary diverticulum, but there is no internal subdivision.

a short, slender duct opens into the first of a series of chambers (p), which is merely a swelling at the anterior end of the "accessory gland" (or "prostate" of authors).

The accessory gland, as Marchand terms it, is a long tubular sac of irregular diameter, of a pale orange colour with a thick glandular wall; internally the lining is smooth, and I found no contents; it reaches back to the apex of the body, not straight, but more or less undulating; its posterior end is very abruptly recurved and slightly enlarged. The length of this gland where extended is 30 mm.

Returning to the complex of chambers that constitutes the "packet", from the enlargement of the accessory gland (marked p) there passes forwards a chamber with indented wall, thick and glandular in appearance (m) which curves round to the right side, bends abruptly on itself, loses its glandular character and, coursing close to and parallel with a chamber (k), enters an enlargement at the anterior end of "Needham's sac."

This complex of chambers m and n corresponds to the structure which Marchand terms the "appendix" of the accessory gland or "rangier druse."

Needham's sac has the usual form and disposition in the body; a long, cylindrical tube, about 15 mm. in length in this specimen: of a pale orange colour. It contained spermatophores. At the anterior end it widens out to form an enlargement into which the end of the "appendix" opens, and from which its continuation forms a somewhat oviform chamber (k) in which were two complete spermatophores, each lying in its own groove along the lining of this chamber, which is thrown into numerous folds.

This chamber (k) suddenly decreases in size and gives outlet to the "penial duct" or "distal vas deferens," and so we reach the penis.

The penis also contained a spermatophore (fig. 14), the "projectile tube" being coiled up in the diverticulum (as described by Marchand, p. 327, and figured).

A comparison of this system with the figures given by Marchand and by Robson show certain very evident differences from all other species.

The "appendix" or blind sac through which the accessory gland communicates with "Needham's sac" is enormously developed, and, in place of its simplicity in other forms, is here subdivided into two distinct regions or differentiations, namely (m) a thin-walled, sacculated chamber and (m') a thick-walled, glandular, more or less cylindrical chamber which opens by a narrow duct into the upper part of Needham's sac.

And it is not only in this individual that this complexity occurs. I find it also in an immature male from Portobello, though the appendix is there less complex. (Fig. 12.)

Spermatophore. It may be desirable to give a brief account of this so remarkable structure, though this account is but imperfect in details. (Figs. 6, 7, 13.) One that was removed from Needham's sac has a length of 40 mm. The enclosed chamber within the thinnish cuticle is divisible into two regions. A broader chamber or "tube"

(*sp*) containing a loose, spirally-coiled mass of spermatozoa, enclosed in the thin horny-brown envelope; and (*pr*) a longer, narrower tube with thicker and double envelope in which is the "projectile apparatus," of a closely-coiled spring. In the figures of this astonishingly complex apparatus I use the terms employed by Racovitza, to whom Marchand refers in the work on the male organs.

To what degree there may be specific differences is not known. However, I give a figure of what I find in *R. australis*.

Explanatory Note of the "Indices" as used by Robson in diagnosing the species of Octopus, and as defined on p. 38 of his Monograph.

A. The length of the "mantle" (or body) is taken from the apex to the middle of the line joining the eyes.

B. The width of the mantle as a percentage of its length.

C. Interocular breadth, i.e., "the distance between the outermost point of the eyes" as a percentage of the mantle length.*

E. Length of the longest arm as a percentage of the *total* length, i.e., length of the body plus that of longest arm.

G. Diameter of largest sucker as a percentage of the mantle length.

J. The web depth; that is the depth of the deepest sector as a percentage of the longest arm (apparently the longest arm of the whole series of specimens, as he only gives one figure).

L. The length of the ligula of the hectocotylus as a percentage of this arm.

It will be seen, therefore, that the determination of species depends on mathematics—a tedious procedure. He also includes the "arm formula" and "web formula," of which he remarks on their comparative unimportance.

Range and Average of the Indices for sixteen specimens of *Robsonella australis*:—

	A	B	C	E	G	J	L
Range ..	10–36 mm.	55–100†	54–81	68–77	11–16	20–31	8.4
Average ..	23	79	62	73	12	24	

For comparison with these I quote the corresponding numbers given by Robson for the six specimens studied by him:—

	A	B	C	E	G	J	L
Range ..	22–33	81–86	62–73	72–76	11–13	33	10.8

The indices for "*campbelli*" fall within the range except that for G, that is the diameter of the sucker, which is 21, for this individual had abnormally large suckers on one arm.

* If a tyro may criticise these terms, one would prefer "supra ocular" width as being more accurate; and "body" rather than mantle, since the latter word is usually used for the "mantle flap" which encloses the mantle or pallial chamber.

† This high figure of 100 is found only in three very small individuals; and excluding these the average is 74.

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A Study of the Little Owl, *Athene noctua*, in New Zealand.

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INTRODUCTION.

THE Little Owl, *Athene noctua*, or, as it is often called in this country, the German Owl, was introduced by the Otago Acclimatisation Society some 36 years ago, in an endeavour to control the numbers of the small introduced birds. According to Thompson, 28 owls were imported from Germany in 1906. Further liberations followed—39 in 1907, 80 in 1908 and 72 in 1910. Owls are also reported to have been liberated in North Canterbury, and in 1911, 66 were obtained by the Waimate County Council, at a cost of £50. A pair was also liberated in the North Island at Rotorua, about the same time, but does not appear to have become established. The bird soon began to increase and spread in the South Island, and before long was accused of being a serious menace to the native birds. At the present time, these accusations are widespread, and rewards are offered for the destruction of the owls.

This history is closely parallel to that in England. The owl, though widespread in the Palearctic region, had only been recorded as a rare straggler in the British Isles. It was introduced into England towards the end of last century, and is at present widespread in England and Wales, except in the north. It is now, if not actually decreasing, probably increasing much less rapidly than formerly. Soon after its introduction, it was accused of killing song-birds and the chicks of game and poultry. It was consequently selected by the British Trust for Ornithology for special study, and a long and detailed report on the investigation by Miss Hibbert Ware appeared in 1938. The result of this investigation was to show that only negligible destruction of game, poultry and wild birds took place, and that the owl fed almost wholly on such insects, other invertebrates and small mammals as can readily be picked up on the ground. The sweeping accusations were shown to be without foundation, though it is pointed out that the feeding habits may have been somewhat different when the numbers were increasing rapidly than at the time of the investigation, when the rate of increase was less. However, a previous investigation of the food, carried out by Collinge in 1918, gave the same results. The bird is regarded as beneficial on the continent of Europe, and is protected in some countries.

When the owl was brought to New Zealand, it was placed in a different environment, and changes, especially in its feeding habits,

might be expected to have taken place. It was therefore decided to study the bird and its feeding habits, taking advantage of the fact that as it was being killed a large number might be obtained, and also that the report of the English investigation was available for comparison. It is not intended to enter into the controversy as to the habits and value of the owl in this country, which has been carried on without any adequate basis of fact. It has been suggested that the present investigation is an attempt to prove that the owl does not eat native birds. No such object is intended, the whole investigation is concerned solely with the accumulation of as many facts as possible concerning the owl and its food, from an examination of the actual birds and of their nesting places and castings. These facts may prove the basis for future discussion. On the other hand, many of the statements which are frequently made about the degree to which the owl destroys other birds, show a remarkable lack of reasoning power or appreciation of the value of evidence. For instance, when it is stated that, as the owl increased, the native birds decreased, it is apparently not realised that these changes, which would need actual numerical data to substantiate them, may be wholly unrelated. Similarly, when it is stated that the screams of birds being murdered by the owls are frequently heard, there is no evidence that the birds really are being murdered, and if so, by whom. A great deal of the so-called "evidence" is of this type. Statements of this kind have been excluded from the present paper, only those giving definite statements of fact being included.

Many of the statements bear so close a relation to ones which remain wholly unsubstantiated in England, that they appear to originate in the English press. It is perhaps worth mentioning some points which were studied in England. The owl is chiefly a twilight and night feeder, and does not habitually feed by day as is often supposed, though it does so occasionally. It is a ground feeder, as is shown by its food. The so-called "larders" are not used for storing excess food, but are more in the nature of "carving holes." Very little evidence of nest raiding has been recorded, and no eggs of other birds have been found in the owl's nests or food. There is no evidence that the owl kills prey and leaves the body to attract beetles which the owl will return and eat later on. These conclusions were reached in England and, though it is of course possible that the owl changed its habits as it became adapted to life in New Zealand, this has not yet been demonstrated. Any reliable information about its habits here would be valuable and should be collected.

Finally, it should be pointed out that arguments as to the economic value or otherwise of the owl are worthless, as none of the requisite data is available. To determine whether the owl is beneficial or not, it would be necessary to know, not only the number of owls present and their food, but also the numbers, food and interrelations of almost all the other animals in the district, as well as the effect of fluctuating conditions of season, climate, etc.

I wish to record my indebtedness to the Royal Society of New Zealand for a grant from the Hutton Fund to defray the cost of

the investigation; to Dr Miller, of the Cawthron Institute, for identifying insects; to Mr Ferguson, of the University of Otago, for assistance with statistical matters, and to all those who assisted by sending in material or information during the course of the investigation.

METHODS.

In response to letters published in the newspapers, offering a reward of one shilling per bird, 243 owls were received between June 23, 1938, and June 26, 1940. Most of them had been trapped or shot, and a few were young, apparently taken from the nest. Though some were considerably decomposed or attacked by maggots, it was possible in all cases but one to examine the stomach contents. The bird was first weighed and in some cases measured. The stomach was then removed and preserved whole in formalin for subsequent examination. In some cases the intestine was opened, washed out, and the contents examined under the binocular microscope for parasites. The length and breadth of the gonads were measured in situ, and these organs were then removed and weighed. Finally, the sternum and limbs of about 100 birds were removed, and the bones cleaned by boiling, for measurement and the study of variations. The results of this will be described in a separate paper.

For the examination of the stomach contents, the stomachs were opened and carefully washed out into a glass dish. All recognisable remains were then picked out under the binocular microscope. Naked eye examination would be useless as in most cases the food is reduced to small fragments, and all soft parts digested. Such things as the chaetae of earthworms or the jaws of small caterpillars are practically invisible to the naked eye, and many things can be recognised only with practice even when magnified. The complete examination of the contents of a full stomach frequently required several hours' work with the microscope. All the fragments, as they were picked out, were placed in another dish containing alcohol, in which they were re-examined and counted, so as to determine the number of individuals present. The material from each stomach was preserved separately in a tube of alcohol.

In addition to the birds themselves, a considerable number of castings or pellets, and debris from nesting holes were received. No attempt was made to examine the invertebrate contents of these, as it was felt that much more satisfactory material was provided by the stomachs. All bones and feathers, however, were picked out. The bones were measured and the measurements compared with a table of measurements prepared from the skeletons of native and introduced birds. The species of birds whose bones were available for comparison were as follows:—Rifleman, Pipit, Fern-bird, Grey Warbler, White-breasted Tit, North Island Robin, Fantail, Whitehead, White-eye, Bell Bird, Greenfinch, Goldfinch, Redpoll, House Sparrow, Thrush, Blackbird, Hedge Sparrow, Starling. The bones were then carefully compared with all the known bones of about the same size and so identified. It is not always possible to be certain of the species to which an isolated bone belongs, but it is possible to distinguish between the bones of different families.

All the material collected during this investigation is preserved in the Department of Zoology of the University of Otago, so as to be available, if necessary, for more detailed study and comparison in future.

Stomach Contents.

The ideal in investigating the diet of any animal is to be able to determine the relative amounts of the basic food materials, carbohydrates, fats and proteins eaten, and the source from which they are derived. In most cases this is impossible, as the foods have not been analysed. Another method is to express the different items as percentages of the total by weight or volume. This method clearly has its disadvantages owing to the large proportion of certain foods which are indigestible—for instance, the soil in the intestine of an earthworm, or the cellulose in that of a caterpillar, but it is more satisfactory than the mere listing of individuals. It is, however, only possible when the food can be recovered unchanged from the gullet or crop of the bird. The great majority of food items recovered from the stomachs of the owls have only been recognised from microscopic fragments, and any attempt to estimate the weight or volume of the very diverse animals represented would be quite valueless. The only possibility, therefore, is to deal with the numbers of individual animals, bearing in mind, in considering their relative importance, both difference in size and frequency of occurrence.

Of the 242 owls whose stomachs were examined, only one contained no food remains of any sort, though several had only one or two minute fragments of beetle skeleton or a few earthworm chaetae. Very few solid particles, even small ones, pass into the intestine, but they are retained in the stomach and periodically ejected as the so-called castings or pellets. Counting each occurrence of chaetae as one worm, which will presumably be an underestimate, 5,443 individual items of food were found, an average of 22.6 per owl. Though insects naturally predominate, the owl exhibits an extreme catholicity of taste, and representatives of all the groups of terrestrial animals are present. Also noteworthy is the small size of many of the animals eaten. The smallest, an oribatid mite smaller than an ordinary pin's head, and a pseudoscorpion, may have been eaten accidentally together with other food, but small spiders, whose length cannot have been much more than a quarter of an inch, were commonly eaten.

It is usual to identify all the species found in such an investigation, but in the present case this was felt to be impossible, and moreover would not be of any great value when only occasionally occurring species are concerned. Only one or two very common species have therefore been identified, and in Table I a number of species will be found included under such headings as "araneomorph spiders," "orthoptera" or "caterpillars." As all the material is preserved, complete identification can be attempted in future should it become necessary.

TABLE I.

The Numbers of Animals Found in the Stomachs of 241 Owls.

Type of Food.	No. of Individuals.	No. of Owls Containing them.	Average No. per Owl.	Average No. per Total Owls.	% of Owls In Which They Occur.	Greatest No. In Any One Owl.
Caterpillars	1936	126	15.3	8.0	52.3%	186
Earwigs	821	26	31.5	3.4	10.8%	267
Lamellicorn Beetles ..	796	90	8.8	3.3	37.3%	73
Araneomorph Spiders ..	271	94	2.9	1.1	39.0%	18
Carabid Beetles	179	60	3.0	0.7	24.9%	27
Mygalomorph Spiders ..	131	18	7.3	0.5	7.4%	57
Lepidoptera	95	41	2.3	0.4	17.0%	10
Weevils	79	23	3.4	0.3	9.5%	21
Cicadas (Adult)	46	11	4.2	0.2	4.5%	14
Opiliones	21	16	1.3	0.08	6.6%	4
Birds	19	22	0.8	0.08	9.1%	1
Total Beetles	1639	211	7.7	6.8	87.5%	74
Total Spiders	404	98	4.1	1.6	40.6%	57
Total Orthoptera	116	16	7.2	0.5	6.6%	53
Total Cicadas	49	14	3.5	0.2	5.8%	14
Total Individuals ..	5443			22.5		296
Invertebrates	5403			22.4		296
Vertebrates	40			0.16		7
Insects	4871			20.2		296
Arachnids	427			1.7		57
Earthworms	(93)			(0.4)		—
Myriapods	7			0.03		1
Crustacea	5			0.02		1
Molluscs	3			0.01		3

Invertebrate Food: Caterpillars.—The commonest insects eaten are caterpillars, which occurred in about half of the owls. Several species are represented but two are commonest and sometimes of large size, up to an inch and a-half or so in length. One owl contained 186 caterpillars in addition to 10 other animals. Most of the bulk of a caterpillar consists of chewed vegetable matter in its capacious intestine, and this material being indigestible by the owl, forms a very conspicuous part of the stomach contents of birds which have been eating caterpillars. Of the caterpillar itself usually only the jaws remain. Most of the caterpillars appear to belong to species which live on the ground, the largest and commonest being the larva of the moth *Persectania ewingi.*

Caterpillars not unnaturally show a marked seasonal periodicity in their occurrence in the stomachs. During the winter, between about March and September, they form an important part of the diet, reaching their peak in June or July, while during the other five months few are to be found.

Beetles.—Nearly as many individual beetles as caterpillars were found, and they occurred at all times of the year, appearing in 87.5 per cent. of the owls. Many different kinds occurred, the most noteworthy being the Lamellicorns, the Carabids and the Weevils,

of which 796, 179 and 79 respectively were found. The Lamellicorns were mostly *Odontria striata* the adult of one of the well known "grass grubs," though another similar but smaller species also occurred. The weevils were *Platyomida sp.* Amongst the others may be mentioned five Elaterid beetles and 12 Longicorns, the large Huhu.

Earwigs.—Twenty-six owls contained earwigs, 14 of them coming from southern bush areas in the Catlins and near Tuatapere. These contained 64 earwigs. Four owls were received from Pembroke and they contained 6, 178, 245 and 267 earwigs respectively, the last two being by far the greatest number of individuals of any animal found in a single stomach. These large numbers are of interest in connection with the opinions expressed by certain fruitgrowers in Central Otago that the owl is beneficial to them because of the numbers of earwigs which it consumes. It is perhaps worth recording that the sex ratio of the 690 earwigs in three Pembroke owls was 60.7 males to 100 females.

Spiders.—Spiders formed a common, though not as a rule conspicuous part of the diet, 404 being recorded from 40% of the owls. Most of them were represented only by isolated chelicerae, but had evidently been quite small. The most interesting feature was the occurrence of the remains of 131 male trapdoor spiders. Those from north of Dunedin were mostly *Arbanitis gillesii,* while those from the south were *A. huttoni.* The males of these are difficult to obtain, but evidently they emerge from their burrows in autumn and are captured by the owls. One stomach contained 57 and another 37 of them. The females apparently do not emerge and none were recorded.

Of the animals only found occasionally, a few deserve special mention. Only five millipedes were found, which, in view of their abundance, is peculiar and suggests that they may be distasteful to the birds or do not emerge while they are feeding. The same applies to woodlice, of which only five were found. One owl contained three slugs, the only molluscs which were encountered, but as it is doubtful if any recognisable remains would be left after they had been in the stomach for any length of time, it is possible that they may be eaten more often than this number suggests. Earthworm chaetae occurred in 93 of the owls, 38% of the total. Anything from one or two to very large numbers were found, but never any trace of the soft parts of the worm.

Comparing the invertebrate food of the owl in New Zealand with that in England as found by Miss Hibbert Ware (1938), a number of differences are apparent. Five insects were found in England to stand out on account of their great abundance. They were a crane-fly *(Tipula sp.),* and earwig *(Forficula auricularia),* a carabid beetle *(Pterostichus madidus),* a dung beetle *(Geotrupes stercorarius)* and a cockchafer *(Melolontha vulgaris).* In New Zealand only one tipulid was found, and if some unidentified black eggs were assumed to belong to these flies, the number would only be raised to five. The earwigs, carabid beetles, and lamellicorns, the last being similar to, though smaller than, the European cockchafer, have already been discussed, while a common dung beetle, corre-

sponding to the English *Geotrupes*, does not occur in this country. Caterpillars occur in the English lists but are not specially mentioned and evidently do not form such an important part of the food as they do here. Other differences are that woodlice, millipedes and small snails are recorded as being common, while in this country they are noticeably infrequent. The work in England was done for the most part on pellet material, but the examination of stomach contents is stated to have given essentially the same results, and the general conclusion was that "the Little Owl feeds to a great extent on what is common on the ground at dusk and by night." This statement apparently holds good for New Zealand also.

It has been suggested that the owl kills birds and leaves the bodies to attract necrophorous insects, visiting the bait from time to time in order to eat the insects. This fantastic story is discussed by Miss Hibbert Ware (1938), who points out that apart from the impossibility of crediting the owl with a degree of intelligence entirely unknown amongst birds, she found only 75 burying beetles in 2,460 pellets and 76 nest-holes. Necrophorous insects are far less conspicuous in New Zealand than in England, so that this habit is, if possible, even less likely to be found here. One stomach contained 28 maggots, but an insectivorous bird such as this is likely to eat carrion insects as well as others should it happen to find them.

Vertebrate Food.—Representatives of all classes of terrestrial vertebrates were found in the stomachs. Two owls contained small frogs, seven in one and one in the other. One contained four small lizards. Twenty-two owls contained remains of birds (three young owls from the same nest containing remains of one bird), nine remains of mice and one unidentifiable pieces of meat with no hairs, feathers or bones accompanying them. Fragmentary rabbit remains were found in three young birds, all sent in together, so probably from the same nest.

TABLE II.

Species of Birds Whose Remains Were Found in the Stomachs of the Owls.

Thrush	6 and	1 doubtful
Blackbird	1	
Starling	1	
Sparrow	1	
Greenfinch	—	1 doubtful
Redpoll	1	
Hedgesparrow	1	
Lark	1	
Fantail	—	1 doubtful
Claw	1	
Gizzard	1	

Unidentified feathers were found in three owls.

Table II gives the bird remains, arranged according to species. The individuals of thrush and greenfinch listed as doubtful are represented only by fragments which are too small to make identification certain. The lining of the gizzard is unidentifiable, but probably belonged to a finch, and three stomachs contained feathers which

did not belong to the owl itself but which could not be identified. The doubtful fantail is represented only by what may be the minute horny sheath of the upper mandible, while the isolated claw belonged to a bird as small or smaller than a white-eye. It will be seen that almost all the birds whose remains were found belong to ground-feeding species.

Vertebrate food occurred most commonly in spring and summer, possibly not only because young birds which are easy to catch are found then, but also because large objects may readily be carried to the nest to feed the young. Fourteen birds occurred between October and January, three between February and May, and two between June and September. Six mice occurred between September and December, three between January and April, and none between May and August. The lizards and frogs occurred in November and December.

Miscellaneous Objects Found in the Stomachs.—A good deal of debris and vegetable matter was found in the stomachs, most of it presumably eaten accidentally with the food. Small stones up to about a quarter of an inch in diameter occurred in 13 owls, and sand or mud in 19. Blades or small tufts of grass were found in 16 birds, and curiously enough 20 contained one or two clover leaves and six contained thistle spines. Another curious feature was the presence of 124 small seeds of various kinds in 35 stomachs. They seem too numerous to have been there accidentally, and yet they were only about 2 mm. long as a rule. Five owls contained seeds with hooked spines belonging to the bidibidi, *Acaena* sp.

TABLE III.

Numbers of Individual Vertebrates Found in the Various Collections of Nest Material and Pellets.

	Sparrow.	Thrush.	Starling.	Pipit or Lark.	Blackbird	Hedgesparrow.	Goldfinch	White-eye.	? Species.	Mouse.	Rabbit.	Frog.
Wallacetown	16	—	1	—	—	—	—	—	—	—	—	—
Otatara	—	—	—	—	—	—	—	—	—	1	1	1
Orepuki	—	—	—	—	—	—	—	—	1	1	1	—
Otekura	—	3	1	—	1	—	—	—	—	1	1	—
Otekura	—	1	—	—	—	—	1	—	—	—	1	—
Pounawea ..	—	1	—	—	1	—	—	—	—	—	—	—
Kaka Point ..	—	—	—	—	1	—	—	—	—	—	—	—
Mosgiel	2	1	—	—	—	—	—	—	—	—	—	—
Patearoa ..	4	—	3	6	—	2	—	—	—	5	1	—
Parnassus ..	1	—	3	1	—	—	—	—	—	—	1	1
Kimbell	—	—	1	—	—	—	—	—	—	—	—	—
Kimbell	—	2	1	—	2	—	—	—	—	—	—	—
Prebbleton ..	6	2	2	—	—	—	—	—	—	5	—	—
Kaiapoi	—	—	—	—	—	—	—	1	—	1	—	—
Kaiapoi	7	1	—	—	—	—	1	—	—	—	—	—
Kahuika	—	2	—	—	1	—	—	—	—	2	—	—
?	—	1	—	—	—	—	1	—	—	—	—	—
Totals	36	14	12	7	6	2	3	1	1	16	6	2

CASTINGS AND NEST CONTENTS.

A number of castings and the contents of nests were received, and as explained above, only the bones in these were studied. It is possible that one or two of the castings may belong to the Morepork, not the Little Owl, but the numbers are not large enough to have much effect on the result. As will be seen from Table III, the remains of 82 birds, 16 mice, 6 rabbits and 2 frogs were obtained. Much the commonest bird-remains were those of House Sparrows, of which 36 were recorded, though it is possible, owing to the great similarity between them, that bones of some of the finches have been included among them. The largest collection of nest material, containing 16 sparrows, was collected by Mr Sorensen at Wallacetown, near Invercargill. The nest was in the wall of a shed in the middle of stockyards, and was occupied for several years in succession. Most of the lark or pipit bones come from Patearoa, a tussock district.

EXPERIMENTS WITH A CAPTIVE LITTLE OWL.

Mr Sorensen, the Director of the Southland Museum, kindly provided some detailed notes on the feeding habits of a captive Little Owl, together with a collection of all the castings produced by it during about six weeks. The owl was fed on earthworms, dead birds, mice and rabbits, and no difficulty was experienced in getting it to eat dead animals. In eating birds it usually removed and ate the head first, but finished the remainder later, leaving only in some cases the primaries. The feathers are more or less completely disintegrated in the stomach of the owl and surround the bones in the castings as a uniform greyish mass. The castings were 1.5 cm. in diameter, and 3 or 4 cm. long, as a rule, though the length was rather variable. A live young rabbit was not touched by the owl, but it ate dead ones, leaving part of the skull, vertebral column, hind leg bones, and stomach.

Similar results were obtained at the London Zoo in experiments carried out by Miss Hibbert Ware (1936). In order to find out what would be done with food too large to swallow she presented her owls with a dead pigeon, but they would not touch it. Mr Sorenson's owl had no hesitation in eating dead young rabbits.

PARASITES.

No special efforts were made to collect ectoparasites from the owls, but a few specimens of fleas and lice were collected. I am indebted to Miss Clay, of the Department of Entomology of the British Museum of Natural History for identifying the louse, which was *Philopterus cursitans* (Nitzsch 1861), a species found on *A. noctua* in Europe also. Dr Karl Jordan, of the Zoological Museum, Tring, kindly identified the flea, *Ceratophyllus gallinae* (Schrank 1803).

The intestine and caeca of 24 birds were opened and their contents examined for endoparasites. The only one found was an extremely slender nematode worm, kindly identified for me by Dr Bayliss, of the British Museum, as *Capillaria tenuissima* (Rudolphi, 1803). Of these 24 birds, 9 had no parasites, 9 had them in the caeca only, 5 had them in the intestine only, and 1 had them in both, a solitary one in the intestine and many in the caeca. The caeca of owls are large and are peculiar in having the closed end expanded into a pear-shaped sac. They usually have dark coloured glutinous contents,

unlike that of the intestine. The caeca only were examined in 20 owls, of which 6 contained nematodes. Infections were not very heavy. The 6 infected intestines contained only 15 worms, while 15 pairs of infected caeca contained 135 worms. This nematode is normally found in *A. noctua* in Europe. Two specimens of the Morepork, *Ninox novaeseelandiae* were also examined.*

It is interesting to find that while the introduced bird has only its introduced parasites, the native owl contained a cestode and two species of nematodes, one a *Capillaria* sp.

Though the numbers are not large enough to be conclusive there is a suggestion that the nematode is more common in the bush districts of South Otago and Southland than in the more open and drier Central Otago and Canterbury. Five birds were received from the Cromwell district and seven from localities in Canterbury. The intestine and caeca of two and the caeca only of the rest were examined and none contained nematodes. As will be seen from the figures given above, among the 32 southern birds examined, one individual out of every three had the parasites in its caeca.

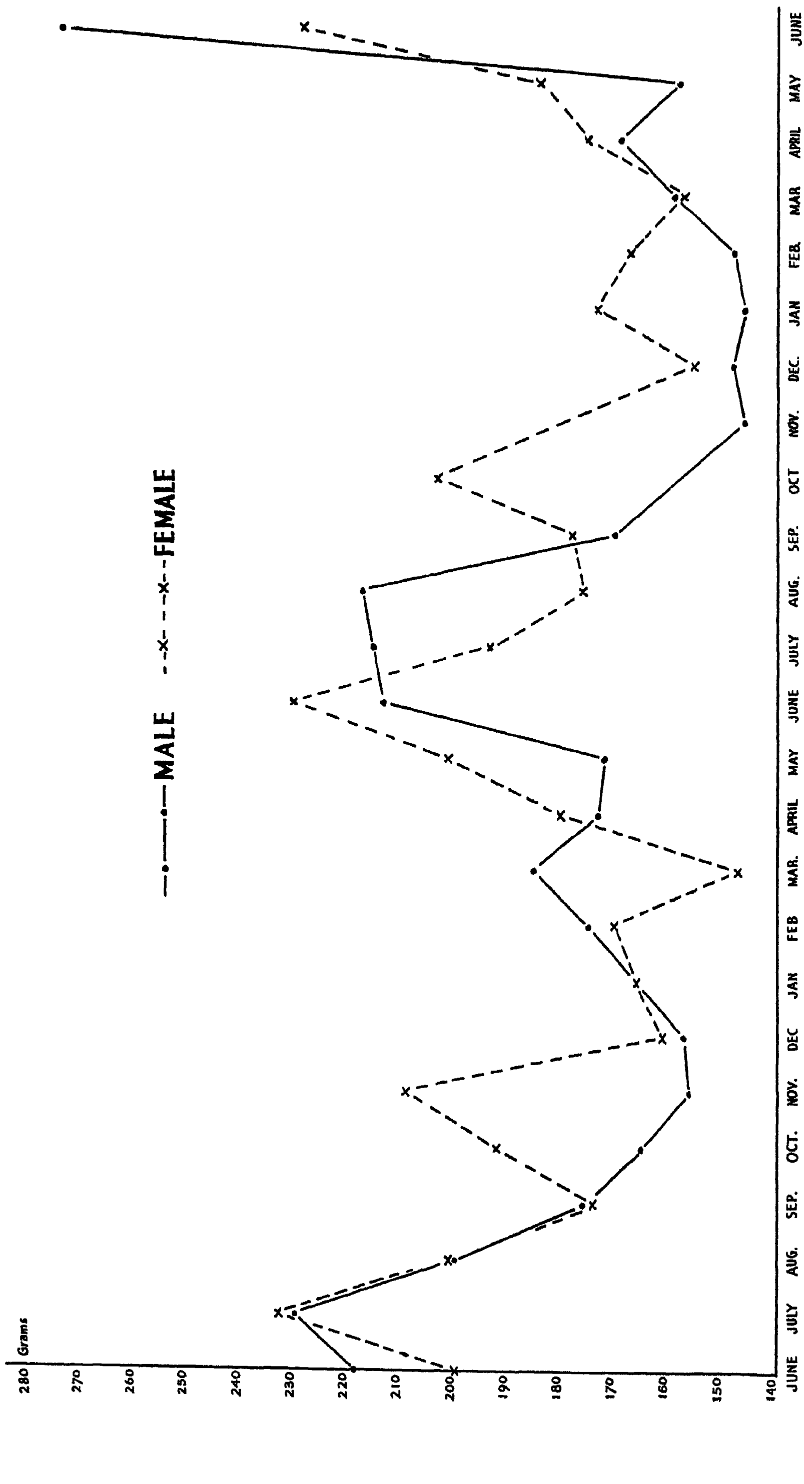
In Europe the owl is known to be the host of certain Haemosporidia. No special attempt was made to look for the presence of these, but the blood of one or two specimens was examined. No blood parasites were noticed.

TABLE IV.

Mean Monthly Weights of the Owls.

	Male.				Female.			
	No. of Birds.	Mean Weight.	Lightest.	Heaviest.	No. of Birds.	Mean Weight.	Lightest.	Heaviest.
June	1	219	—	—	1	200	—	—
July	3	230	203	253	2	233	227	238
August ..	3	200	198	201	2	201	175	227
September ..	2	176	166	186	6	174	141	189
October ..	6	165	143	187	4	192	174	231
November ..	4	156	142	180	2	209	189	229
December ..	9	157	148	175	6	161	139	177
January ..	—	—	—	—	2	166	142	191
February ..	6	175	139	203	13	170	163	181
March ..	7	185	141	216	2	147	143	151
April ..	7	173	142	192	8	180	148	210
May	6	172	146	191	9	201	173	220
June	4	213	212	215	9	230	142	298
July	2	215	206	225	3	193	167	210
August ..	2	217	208	227	1	176	—	—
September ..	1	170	—	—	4	178	164	211
October ..	—	—	—	—	1	203	—	—
November ..	1	146	—	—	—	—	—	—
December ..	2	148	145	152	2	155	149	161
January ..	1	146	—	—	1	173	—	—
February ..	1	148	—	—	1	167	—	—
March ..	6	159	148	178	5	157	147	169
April ..	17	169	148	193	17	175	154	206
May	1	158	—	—	1	184	—	—
June	1	273	—	—	2	228	223	234

* It should be noted that neither of these Moreporks met its death because of the investigation. One was found dead and the other was killed in mistake



Graph showing the monthly changes in mean body weight of the two sexes during the period June, 1938, to June, 1940.

WEIGHT.

The weights of the owls varied considerably during the year, being highest in winter, when in some cases an extraordinary amount of fat was to be found not only around the viscera but also forming a thick layer below the skin. The two sexes are similar in weight, as they are in size. The weights of 93 males ranged from 139 to 273 grms., while the limits in the case of 104 females were 139 and 298 grms.

The birds were weighed just as they were received, so that some variation in weight is due to the amount of food in the stomach. In order to find out how far this affected the result, the stomach contents of two birds with unusually full stomachs were weighed. The total weights of the birds were 174 and 170 grms, and the weights of their stomach contents were 4.3 and 4.5 grms. respectively. Clearly the weight of the food in the stomach will not interfere with the use of gross body weights in the study of the seasonal variations, which are of the order of 100%.

The changes in weight from month to month are shown in Table IV and the graph. The figures plotted are the mean weights, and it will be seen from the table that the monthly number of birds varies from 1 to 17, the mean being about 4. In spite of the smallness of the samples the shapes of the graphs for the two years are similar, and so it seems probable that the true changes are shown.

In the male the weight falls steadily from a maximum about July until November, when it remains low and more or less the same for two or three months. Then it rises again towards the winter maximum. There is, however, a minor loss in weight about April or May, interrupting the upward trend. The curve for the female is of similar shape except for a sudden and very marked increase in the spring, about October or November. The minor loss in weight in the autumn occurs one or two months earlier in the female than in the male. As the moult takes place in autumn it is reasonable to assume that this loss in weight is associated with it. This is confirmed by the fact that of the birds recorded as being in moult before March 1, eight were females and four were males; of those after March 1, seven were females and 15 were males. The high average weights of the females in October and November are partly due to the presence of a few very heavy birds, but even if these are excluded the average weight of the remainder is above that of the males. This increase in weight of the females is clearly connected with the changes in metabolism during the development of the ovary, and perhaps also to the period of enforced inactivity during incubation.

The same general form of curve showing the seasonal changes in weight has been found in a number of different birds. Nice, working with the Song Sparrow, *Melospitza melodia,* found a winter maximum for both sexes in January. The weight decreased during the spring in both sexes, but the females showed an increase during laying and incubation, as in the owl. Similar seasonal changes are recorded in other passerine species.

TABLE V.

Mean Monthly Weights of Ovaries and Testes.

	Ovary.				Testis.			
	No. of Birds.	Mean Weight.	Lightest	Heaviest.	No. of Birds.	Mean Weight.	Lightest	Heaviest.
June	1	0.050	—	—	1	0.030	—	—
July	2	0.075	0.07	0.08	3	0.026	0.02	0.03
August ..	2	0.070	0.02	0.12	3	0.036	0.03	0.05
September ..	6	0.175	0.06	0.29	—	—	—	—
October ..	4	0.565	0.23	1.50	5	0.242	0.10	0.34
November ..	3	0.576	0.14	1.21	3	0.113	0.04	0.21
December ..	4	0.077	0.04	0.12	5	0.024	0.01	0.04
January ..	1	0.040	—	—	—	—	—	—
February ..	13	0.027	0.02	0.07	6	0.013	0.01	0.02
March ..	1	0.020	—	—	7	0.022	0.01	0.05
April	10	0.031	0.02	0.05	9	0.016	0.01	0.02
May	9	0.041	0.02	0.08	6	0.024	0.01	0.06
June	10	0.054	0.04	0.08	3	0.026	0.02	0.04
July ..	3	0.066	0.03	0.09	2	0.020	0.02	0.02
August ..	—	—	—	—	3	0.053	0.04	0.06
September ..	3	0.150	0.10	0.21	1	0.180	—	—
October ..	1	3.520	—	—	—	—	—	—
November ..	—	—	—	—	1	0.050	—	—
December ..	2	0.045	0.04	0.05	1	0.050	—	—
January ..	1	0.050	—	—	1	0.020	—	—
February ..	—	—	—	—	—	—	—	—
March ..	3	0.023	0.02	0.03	1	0.010	—	—

SEASONAL CHANGES IN THE GONADS.

In Table V are shown the mean weights of the gonads of the owls for each month. It will be seen that the usual avian changes are shown, the ovaries and testes about February or March being completely regressed and about equal in weight. Up to August the testes remain about the same, while the ovaries increase slightly. Then comes a tremendous increase in size and weight to the maximum in October or November, followed by an equally sudden decrease. The limits of weight are 0.02 and 1.50 grms. in the case of the ovary, and 0.01 and 0.34 grms. in the case of the testes. By comparison with the graph of body weight it is seen that the spring increase in weight of the female accompanies the increase in the ovary. It is not caused directly by it since the ovary only weighs some three grammes, and the mean body weight of the female at this period is at least 30 grammes more than that of the male. The increase in size of the testes is not accompanied by increased body weight in the male, nor are the changes in body weight accompanying the moult reflected in changes in the gonads.

At its smallest, the ovary measures roughly 8.0 x 4.0 mm. The eggs in it vary in circumference in different birds, those in which they are less conspicuous being possibly young birds which have not yet bred. Nine ovaries were recorded with dark spots on them, which

might have been due to the degeneration of eggs or egg-follicles after breeding. Four individuals were noticed in which the right ovary was present, but it was always small, measuring about 3.0 x 1.5 mm. In two of them, three or four small eggs were visible.

The size of the testes varied between 2.0 x 1.5 mm. and 3.5 x 2.0 mm. for the right and left organs respectively, to 9.0 x 7.0 mm. and 11.0 x 8.5 mm., the left always being larger than the right. Normally the testes are pale coloured, even when in the regressed condition, but four exceptions were noted. In two, one testis was black, in one the testes were dark coloured, and in the other they had black spots on them.

MISCELLANEOUS.

The numbers of the two sexes obtained, including both immature and adult birds, were 114 males and 125 females. This is a sex ratio of 91.5 males to 100 females.

The breeding females had a large bare brood-patch, about 120 x 65 mm. Laterally the knees were bare and the apterion extended up to the axilla. Seven females were received having the brood-patch, one apparently in the middle of laying. One male (15/1/40) had what appeared to be the remains of a brood-patch, and was assumed to be a female until it was dissected.

Six eggs were received, their measurements being as follows:—33.6 x 28.8, 33.9 x 29.6, 34.7 x 29.0, 35.6 x 28.7, 35.8 x 29.0, 37.6 x 28.7 mm. The first two came from one nest, the rest from another. These measurements are within the limits given by Witherby for 67 British eggs.

Some of the birds were measured. The wing was measured by laying it along a ruler and straightening and flattening it as much as possible, the length being taken from the carpal bend to the tip of the longest primary. The tarsus was measured from the upper side of the base of the middle toe to the back of the heel, the measurement being therefore somewhat greater than the length of the tarsal bone itself. The middle toe was measured from the upper side of the base to the tip of the claw. The beak was measured from the tip to the cere, a region referred to below as the culmen, and from the tip to the feathers, a distance referred to as the beak.

TABLE VI.

External Measurements of Owls.

		Number Measured.	Mean.	Limits.	Standard Deviation.
			mm.	mm.	
Wing	♂	45	166.7	157 –179	55.90
	♀	45	169.1	158 –180	17.97
"Tarsus"	♂	44	39.9	38.0– 42.0	1.050
	♀	43	39.8	38.0– 42.0	1.145
Toe	♂	47	30.6	27.0– 33.0	1.220
	♀	45	30.6	29.0– 32.0	0.283
Beak	♂	45	19.3	17.0– 21.0	0.238
	♀	41	19.2	18.0– 20.0	0.175
Culmen	♂	39	14.8	13.5– 16.0	0.197
	♀	36	14.6	13.0– 16.0	0.189

The details of all these series of measurements are shown in Table VI. The male is in each case more variable than the female. The variation is especially marked in the case of the wing, where the distribution of lengths shows little or no resemblance to the normal distribution curve. It is possible that immature birds may have been included though they were omitted whenever recognisable. There appears to be no difference in size between the two sexes as shown by the mean lengths of these various parts, the greater length of the female wing being obviously not significant. (Actually the probable error of the difference is 5.8, while the actual difference is only 2.4). Witherby gives the following measurements from British specimens: Wing—male 153–165 mm. and female 156–165 mm., there being 20 and 18 specimens respectively. Beak—male, 18–21 mm. The upper limit of the New Zealand wing measurements is considerably higher and the lower limit slightly so, but the numbers are small, and the difference may be accounted for by a slight difference in the method of measuring.

For comparison it may be stated that Hicks, studying the variations of a large number of Starlings, *S. vulgaris vulgaris,* in Ohio found that the males had a somewhat greater range of size variation than the females for all measurements. Out of 10,000 birds, he found that 5.35% had physical deformities. Only one abnormal owl was found in the present investigation. In it the hind claw, instead of being curved and about 10 mm. long, was quite straight and 7.5 mm. long. Only one diseased bird was found. It appeared to be in good condition, though perhaps moulting late, and was heavy for the time of year, but the liver and spleen were pale and much enlarged and thickly covered with fatty-looking nodules. There was a good deal of soft yellow fat in the region of the post-hepatic septum, and a fatty adhesion on the right side, apparently at least partially obliterating the thoracic air sac. The testes were rather larger than usual for the time of year but looked normal, as also did the intestines and kidneys. Dr Sutherland, of the Department of Pathology, kindly examined this specimen and reports that it was suffering from tuberculosis, large numbers of tubercle bacilli being visible in the lesions.

Information Received from Correspondents.

In response to appeals in the press for information about owls, some 60 letters were received, and of the considerable number of questionnaires sent out, 26 completed forms were returned. The information from these sources has been analysed below, but it must be remembered that it is evidence of a different nature from that provided by the actual stomach and nest contents. It is accordingly kept in a separate section.

The information is not sufficiently extensive to give a very detailed knowledge of the distribution of the Little Owl, but it is predominently in the south-eastern part of the South Island. It is reported to be present at Puysegur Point, in the south-west, and at Parnassus, in North Canterbury. All the other records except two lie to the south of a line joining the two places, the exceptions being at Pembroke, just west of the line, and at Inchbonnie, in Westland. The more mountainous regions lie to the north of this line, but

whether the absence of records is due to the absence of owls or of observers is not at present certain. It is stated to have been absent at Lake Kanieri, in Westland, in 1929. It is reported to be common both in bush districts, such as the Catlins, and to the west of Invercargill and in the treeless Central Otago. It is also frequently found in the willow trees along the banks of rivers.

In the North Island a pair of owls was liberated at Rotorua about 1910, but soon vanished. There seem to be no specimens from the North Island, and the owl is usually stated to be absent. Four letters have, however, been received stating that it is present in the southern part of the North Island, and the matter requires further investigation. One observer states that it had been present at Te Marua, 23 miles north of Wellington, for four years in 1938, and had been seen eating snails. The Morepork was stated to be also present. Another observer, who had known the bird in England, states that he saw it in 1934 at the mouth of the Otaki River, and in 1935 near the Ohau River. Another records it as not plentiful, but present for 15 years, in the Waitohu Valley, three miles from Otaki, and another possible record is from Palmerston North.

General impressions as to the changes in numbers of birds from year to year are of little or no value, only the results of actual counts are to be relied upon, and none of these have been made. Nine out of 23 informants state that the owl is increasing in their district, but four reports are contradictory. These districts are towards the edge of the inhabited area, while there are three reports of decrease towards its centre. Though little reliance should be placed upon such reports, it may perhaps be suggested that the owl increased and spread rapidly soon after its introduction, and that at present both its numbers and its range are only increasingly slowly. From the majority of places the bird is reported to have been present 15, 20 or even 30 years, and it is only about 35 years since it was introduced.

Collaborators were asked to state whether they had actually seen the owl catch birds. The numbers of reports of different birds seen to be taken were as follows:—Sparrow, six; Blackbirds, four; White Eye, two; Thrush, Goldfinch, Chaffinch, Starling and "Tit," one each. One observer had seen an owl chasing a sparrow, and another chasing "birds." One recorded an owl taking the bodies of blackbirds which had been shot, and another an owl feeding on a dead hare. The nesting sites recorded are as follows:—Hollow trees, 12 hollow logs, rabbit holes and stacks, 4 each; clay banks, 3; crevices in rocks and the walls of old sheds, 2 each; caves, 1. The different numbers of eggs or young in a nest were found the following number of times:—Two eggs or young, 7 times; three eggs or young, 9 times; 4 eggs or young, 10 times; 5 eggs or young, twice. Miss Hibbert Ware states that of 17 records in England, two eggs or young were found 6 times; three eggs or young, 6 times; and 4 eggs or young, 5 times. She also states that there is reason to believe that more eggs were layed some years ago, and that this diminution is connected with the slower rate of increase of the owl compared with that which it had during the first few years after its introduction into England.

TABLE VII.

List of Vertebrates Mentioned in the Text, with Their Scientific Names.

Frog, *Hyla aurea.*
Lizard, *Hoplodactylus sp.*
Morepork, *Ninox novaeseelandiae.*
Little Owl, *Athene noctua.*
Pipit, *Anthus novaeseelandiae.*
"Tit," ? *Petroica macrocephala.*
Fantail, *Rhipidura fuliginosa.*
White Eye, *Zosterops halmaturina.*
Greenfinch, *Chloris chloris.*
Chaffinch, *Fringilla coelebs.*
Goldfinch, *Carduelis carduelis.*
Sparrow, *Passer domesticus.*
Thrush, *Turdus ericetorum.*
Blackbird, *Turdus merula.*
Hedge Sparrow, *Prunella modularis.*
Lark, *Alauda arvensis.*
Starling, *Sturnus vulgaris.*
Mouse, *Mus musculus.*
Rabbit, *Oryctolagus cuniculus.*

SUMMARY.

1. The stomach contents of 242 Little Owls, *A. noctua,* were examined. Remains of 5443 animals, belonging to practically all terrestrial groups, were obtained. Caterpillars and beetles formed the most numerous constituents. Remains of 20 birds, 9 mice, 4 lizards and 8 frogs were found. With two doubtful exceptions, none of the birds were native species.

2. Vertebrate remains were collected from 17 samples of castings and the contents of nests. They contained 82 birds, 16 mice, 6 rabbits and 2 frogs. All the birds were introduced species, with the exception of 1 white-eye and perhaps 7 individuals which were either larks or pipits.

3. Some owls were examined for endoparasites. Only the Nematode *C. tenuissima* was found.

4. The seasonal variation in weight was studied, the maximum being in June or July.

5. The seasonal variation in gonad weight was studied.

6. The sex ratio was 91.5 males to 100 females.

7. Only one abnormality, a straight claw, and one diseased bird were noted. The diseased individual was suffering from tuberculosis.

8. Measurements of about 45 birds of each sex are given. There is no sexual difference in size.

9. Replies from correspondents with reference to distribution, nesting and feeding are analysed. Out of 17 birds seen to be taken, 3 only were native species, 2 white-eyes and 1 "tit."

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The Anatomy and Systematic Position of *Temnocephala novae-zealandiae* Haswell.

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INTRODUCTION.

THE genus *Temnocephala* occurs mainly in the Southern Hemisphere, where it has a very wide distribution, being found in Australia, New Zealand, New Guinea, East Indies, and South America. In the Northern Hemisphere it is known only in Mexico. It was first recorded for New Zealand by Wood Mason (1875), but it was not till 1888 that Haswell (1888) listed *Temnocephala novae-zealandiae* as a new species. Later, Haswell (1893) published a further account with figures of the external and internal structure of *Temnocephala novae-zealandiae,* and more recently (1924) he revised the structure of the female reproductive organs. The most complete general accounts of the group are those given by Merton (1914, 1922) and by Bresslau and Reisinger (1933) in Kükenthal's *Handbuch der Zoologie,* but these writers as well as Haswell relied mainly on preserved material, especially for *Temnocephala novae-zealandiae,* with the result that the description of the New Zealand species is in part incomplete. In view of this and of the fact that Kükenthal and Merton's papers are not available in New Zealand, it was decided to publish a concise account of the New Zealand species based on the study of living as well as preserved material.

MATERIAL AND METHODS.

Temnocephala novae-zealandiae is found at all times of the year on the body and appendages of the freshwater crayfish, *Paranephrops neozelanicus,* the majority being attached to the great chele, where no doubt they received a certain amount of protection from the long setae. When removed from the host they are able to live for several weeks in fresh water without aeration, and for a much longer period in aerated water. The eggs are laid throughout the year and are attached by one end to all parts of the crayfish.

Fixing. Various methods were tried, the most satisfactory being that of Wilhelmi (Lee 1937, par. 1210). According to this method, the animals are covered with almost boiling Zenker's fluid and flattened under a glass weight. After about 30 minutes in the fixative the animals are removed to water for some hours and then passed into iodine alcohol.

Staining. For whole mounts, HCl-Carmine gave the best differentiation, and for sections Mallory's triple stain was most satisfactory for general work. Heidenhein's Iron Haematoxylin was useful for histology, while Biebrich Scarlet is an excellent plasma stain and made a good contrast with Celestin Blue.

External Features.

Temnocephala novae-zealandiae has six tentacles instead of the usual five. The young, immature animal is whitish except for the conspicuous dark brown intestine lying across the body; but as the animal becomes sexually mature, its colour changes to greenish-grey or brown according to the amount of yolk present. The length of the animal varies according to its age and extension, the body of a large, fully extended specimen measuring six millimeters. At the posterior end of the ventral surface is the large, stalked, ventral sucker and in front of it is the common genital pore. The mouth is also ventral and lies just behind the base of the tentacles. Dorsally, there is a pair of eyes at the anterior end, and at the sides, just behind the level of the eyes, lie the two excretory pores.

INTERNAL ANATOMY.

(a) Body Wall and Glands.

The body wall is not characteristically turbellarian. It is not ciliated, although Haswell (1893, p. 99) has observed cilia in other species, and there are no glands in the epidermis. There is a striated cuticle outside the epidermis which is here a syncytium with widely-scattered nuclei. Haswell (1893) and Merton (1914) both describe elevations, sensory and otherwise, on the cuticle. I cannot find any in an extended animal, although when the animal is contracted, the cuticle is uniformly crinkled all over. The epidermis rests on a wide basement membrane under which lie circular, diagonal and longitudinal muscle-layers in that order, with the band of longitudinal muscles much broader ventrally than dorsally.

Although no glands lie in the epidermis itself, a number of gland cells are situated in the parenchyma and have long ducts opening on to the surface of the body. There are three regions on which these ducts open:—(1) Tentacular, (2) sucker, (3) genital pore.

(1) *Tentacular Glands.* (Pl. 21, t.g.)

In most species of *Temnocephala* these glands lie dorsally and are scattered along the sides of the body from the excretory vesicle to the anterior testis, but in *Temnocephala novae-zealandiae* the gland cells of each side are usually aggregated into two compact bodies lying one behind the other at the sides of the intestine. Each glandular body or gland is ovoid in shape and is enclosed in a thin muscular sac. The gland cells inside have large vesicular nuclei and are irregular in shape, their boundaries being more or less marked by dorso-ventral muscles.

The secretion consists of mucus containing short, shiny rods which are the rhabdites characteristic of Turbellarians. The rhabdites take a bright red stain with Mallory, so that the course of the ducts to the exterior can be easily traced. Strands of ducts (pl. 21, t.d.) go forward from the glands of both sides and meet at the base of the tentacles in front of the eyes. From here the ducts pass into the tentacles in regular fashion, two strands to each tentacle where the ducts separate out and open on the ventral surface mainly at the tips of the tentacles. The mucus is often squeezed out of the ducts in the form of coiled threads which appear to be quite firm and solid and must be useful in entangling prey; the function of the rhabdites in the mucus is more difficult to explain unless they strengthen the entangling mesh.

(2) *Sucker Glands.*

There is a pair of Sucker glands (pl. 21, s.g.) at the sides of the posterior end of the body They are not so compact as the Tentacular glands nor so deeply staining and the secretion is granular. There are no rhabdites. From the glands, ducts run in strands to the centre of the sucker, and passing through the stalk spread out and open all over its ventral surface. Both the Tentacular and Sucker glands are very important in locomotion, the animal moving very quickly with a looping action. When not travelling it remains attached by the Sucker gland, and stretching out to its full length swings round in a semicircle, reaching far forward with its waving tentacles. Both glands are useful, too, in attaching the animal firmly to its host, which darts about with sudden, quick movements.

(3) *Genital Glands.*

These will be described in connection with the reproductive organs.

(b) NERVOUS SYSTEM.

The nervous system follows the general platyhelminth plan and is very similar to that of planarians. There is an outer and an inner nerve net surrounding the body, the outer net lying immediately under the epidermis, the inner and much thicker net lying immediately inside the inner longitudinal muscles. The two nerve-nets are connected by fibres all over the body. The inner nerve-net is thickened to form three pairs of longitudinal nerve-cords, a dorsal, a ventral, and a lateral pair. The longitudinal cords are connected by transverse cords, and diagonal cords connect the dorsal and ventral portions. The nerve-nets contain nerve-cells and processes as do the nerve-cords, which thus differ from nerves of higher animals which are composed of nerve fibres only. The cells in the nerve-cords are more differentiated than those of the nerve-net, many being bipolar so that an impulse can pass in one direction only.

The " brain " is a broad, thick, horizontal band of nervous tissue lying dorsally just in front of the pharynx. It is merely a concentration of the nerve cords and contains the bodies of nerve-cells and tracts of fibres. The " brain " sends nerve cords to the tentacles and receives sensory nerves from the two eyes (pl. 21, e.), which lie in front of, and slightly dorsal to the " brain." Each eye consists of a double pigment-cup lying transversely to the body, with a concavity at each end. There is a single pigment-cell and one retinula in each cup. The retinula-cell completely fills the cavity of the cup, the nucleus lying just outside the brim, from which the cell tapers to form a nerve fibre going to the " brain."

Sense cells occur over the whole body and are connected with the nerve-nets or nerve-cords.

(c) ALIMENTARY CANAL.

The so-called mouth appears as a transverse slit on the ventral surface of the body near the anterior end. It leads through a muscular pharynx and short oesophagus into a wide saccular intestine occupying the middle part of the body. According to Fernando (1934), the pharynx is ectodermal in origin but not stomodeal, and

the oesophagus and intestine are endodermal. Using Goodrich's (1935) nomenclature, the entrance to the pharynx is the true mouth (pl. 21, m.) and the entrance to the oesophagus is the enterostome (pl. 21, en.). In the retracted condition, the true mouth lies well below the surface of the body, and the skin above it is folded so as to allow the pharynx to be protruded, the amount of folding varying in different species. From this aspect von Graff (1908) has established three types of pharynx for Rhabdocoels—simplex, bulbosus and plicatus. *Temnocephala novae-zealandiae* has a pharynx bulbosus (pl. 21, ph.), over the anterior end of which the skin forms a pharyngeal sheath (pl. 21, ph.s.).

The epithelium lining the depression leading into the pharynx is a continuation of the body epithelium but contains gland cells in addition to the epithelial cells. At the outer margin of the pharyngeal sheath it changes abruptly to the very distinctive pharyngeal epithelium which covers the anterior end of the pharynx and lines its cavity. The pharyngeal epithelium is a wide, deeply-staining layer without apparent structure and without nuclei. It has been variously described as cuticle only, as a syncytium, or as a degenerate epithelium with only occasional degenerate nuclei or with no nuclei at all. The various pores and strings of granules described by both Haswell (1893) and Merton (1914) as appearing in the epithelium are not visible in any of my preparations and are possibly artefacts. Since this layer rests on a basement-membrane as is the case with epithelium generally, it would appear to be here not a cuticle but an epithelium which has become highly specialised for the work it has to do in holding and crushing prey.

The pharynx is enclosed in a connective-tissue capsule, and between that and the epithelium are several muscle layers. There is a narrow circular and a narrow longitudinal layer on the outside, and similar layers lie next to the epithelium. Between these outer and inner sets of muscles there is a wide band of radial muscles. Scattered among the radial muscle-fibres are large nuclei like those of the parenchyma-cells. These nuclei are all very similar, and I am unable to distinguish the three types of cell, myoblasts, gland-cells, and nerve-cells described by Merton (1914, p. 28) for *Temnocephala novae-zealandiae.* A small sphincter muscle surrounds the so-called "mouth," and strong anterior and posterior sphincters control the openings of the pharynx.

The oesophagus is very short and inconspicuous. In transverse section the cavity appears to be very small, but the walls are deeply folded so as to allow for great extension. Beyond having a sphincter of circular muscles it is not marked off in any way from the surrounding parenchyma. Numerous unicellular salivary glands lie in the parenchyma between the pharynx and the intestine, and their ducts enter the oesophagus both on the ventral surface where the gland-cells lie free, and at the sides where the cells are grouped together into solid clumps.

The intestine (pl. 21, i.) is a wide sac in which may be distinguished a smaller median portion with a large pouch on each side. Each pouch is partially subdivided into about six smaller pouches by connective-tissue septa which project into the cavity from the

intestinal wall. There is a very thin layer of circular and longitudinal muscles on the outside of the intestine, but it is the lining epithelium which comprises the main thickness of the wall. It consists of elongated cells with nuclei at the outside, the size of the cells varying greatly in proportion to the amount of food which the animal has recently eaten. Among the epithelial cells are numerous digestive gland cells which empty their secretion into the cavity of the intestine.

(d) EXCRETORY SYSTEM.

The excretory system consists of flame cells, branched excretory canals, and a pair of oval excretory vesicles (pl. 21, ex.v.) which open to the exterior on the dorsal surface near the anterior end, in a similar position to that of the Graffillidae, a family of the Rhabdocoel sub-order Dalyellioida. The lumen of the excretory vesicle does not correspond to the outline, but is in the form of a wide s-shaped tube running along the length of the vesicle and receiving at the posterior end a short, more or less transverse, collecting canal. The wall of the vesicle consists of a firm layer of tissue on the outside and lining the cavity, with between the two a loosely fibrillated layer. Haswell (1893) describes the outer layer as being composed of circular muscles used for emptying the vesicle. In all my stained preparations this layer appears quite different from the ordinary muscle tissue, moreover the vesicle is emptied not by the separate contraction of its wall, but by the contraction of the whole animal.

A series of extremely fine branching canals extend from the outer layer to the inner lining, through which they pass and open into the cavity of the vesicle. Haswell (1893) considers that these fine canals join and enter the main anterior excretory canal at a definite point on each side. I could find no such connection, and the function of these fine canals seems to be quite obscure.

At the posterior end of the vesicle are two large nuclei close together. These are the only nuclei found in the vesicle and from their position it has been presumed by Halswell (1893), Merton (1914) and others that one is the nucleus of the vesicle which is thus a single cell, and the other is the nucleus of the cell which forms the collecting canal. The whole excretory system is intracellular, and nuclei can be seen at intervals in the walls of the main canals.

The collecting canals divide into anterior and posterior longitudinal canals lying at the sides of the body. The two anterior canals join in front of the eyes and from this connective a branch runs up the axis of each tentacle. The posterior canals are connected behind the pharynx and intestine, and from all these main vessels branches are given off in all directions.

Flame-cells were observed at the ends of some of the terminal branches on the tentacles and in other parts of the body. These are the "wimperflammen" of Haswell (1893), who saw only the flame, but there is no reason to believe that they are not typical flame-cells. There are also a number of flame-cells (thirty or more) in the wall of the excretory vesicle. What their function here is I do not know, nor if they are connected with the fine canal system of the vesicle. Haswell gives no explanation and Merton, who had no living material;

was unable to see flame-cells at all. Bresslau and Reisinger (1933), in describing the excretory system of the group *Temnocephala* as a whole, state that the excretory vesicle is lined with cilia and that the terminal branches of the excretory vessels end in cells with " treibwimperflammen ".

According to Haswell (1893), some of the terminal branches of the canals end in nephridial cells, of which he found four types. Merton (1914) found only one type of cell which he thought might be nephridial cells (there were about twenty of these cells), but which were unlike any of Haswell's types. Bresslau and Reisinger (1933) consider that the cells figured by Merton (1914) correspond to the paranephrocytes already seen in the Typhloplanioida, the Dalyellioida and the Kalyptorhynchia among the Rhabdocoels and from this assumes that similar cells may exist in another closely allied order, the Temnocephalida. I have seen cells in stained sections which resemble both Haswell's and Merton's drawings, but I can find no connection between these cells and the excretory canals as Haswell suggests. On the other hand, recent experimental work on the Turbellaria (Bresslau 1933) shows that in the groups so far investigated the nephridial cells or paranephrocytes are not connected with the excretory canals at all, but are wandering cells in the parenchyma, where they collect the excretory material and carry it to the intestine, whence it is emitted with the faeces. A small amount of excretion may take place through the walls of the excretory canals to be washed out by the excess water removed from the body by the flame cells.

The whole problem of the excretory system and its mode of action in *Temnocephala* is still unsolved, although the canals themselves and the flame-cells can be well seen in young animals. More experimental work requires to be done on other members of this group, particularly on the closely-related Didymorchids, and the results compared with those recorded for other Platyhelminths.

(e) Reproductive Organs.

(1) *General.*

The common genital pore (pl. 22, g.p.) is connected by a narrow passage in the muscular body-wall with the genital atrium (pl. 22, g.at.) which lies in the parenchyma about mid-way between the dorsal and ventral surfaces. Into the atrium open the two genital ducts, the male on the left, the female on the right. The male copulatory apparatus and the female organs, each surrounded by its own parenchyma, lie directly in front of the genital pore behind the narrow median part of the intestine.

(2) *Male Organs.*

The male organs consist of a pair of testes on each side of the body with a vas deferens from each pair joining its fellow in the middle line to form a seminal duct. The seminal duct enters a seminal vesicle from which the sperms pass through a granular vesicle (vesicula granulorum of von Graff) into the ejaculatory duct opening through the penis into the genital atrium. Ducts from prostate glands enter the granular vesicle.

The oval testes (pl. 21, te.) lie in the parenchyma at the sides of the body, an anterior pair about halfway along the body, and just behind them a larger pair from which the vasa deferentia (pl. 22, v.d.) arise as wide, thin-walled tubes usually filled with spermatozoa. Each anterior testis is connected with the one behind by a narrow duct so that spermatozoa from the anterior testis must pass through the posterior one in order to reach the vas deferens. The two vasa deferentia join to form a median duct which runs forward beside the penis. Haswell (1893), Wacke (1903) and Merton (1914) call this median duct the seminal vesicle, but I prefer to reserve that term for another structure and to call this duct the seminal duct (pl. 22, d.s.), bringing it into line with similar ducts described by von Graff (1904–08), both for Planarians and Rhabdocoels. The proximal part of the seminal duct is wide and filled with spermatozoa, thus corresponding to the "false vesicula seminalis" of the Planarian *Geoplana marginata* and the Rhabdocoel *Macrostomum tuba* where the true seminal vesicle is a completely different structure. The distal part of the seminal duct is narrow and contains few spermatozoa. The walls of the vas deferens and seminal duct are similar in structure, with an outer layer of circular muscles and an inner epithelium with flattened nuclei.

The seminal duct enters the junction between two more or less spherical vesicles through a very small opening on the ventral surface. The anterior vesicle (pl. 22, v.s.) is the true seminal vesicle and, in sections, is seen to contain a very few spermatozoa. Its position corresponds exactly to that of the seminal vesicle described by von Graff (1904–08, p. 2274) for Rhabdocoels, and it has a specially muscular wall for forcing out the spermatozoa, such as is found in the seminal vesicle of Planarians where also as a result of the contraction of these muscles, spermatozoa are not found in preserved material. The muscles are arranged with an inner circular layer and a wider outer longitudinal layer from which radiating muscle bands converge to a point dorsal to the vesicle, these no doubt helping too in the discharge of spermatozoa. Haswell (1893) names this vesicle the ejaculatory sac on account of the fact that it usually contains a small number of spermatozoa. Wacke (1903) describes it as a second seminal vesicle, but Merton (1914), while denying that it is a seminal vesicle, is unable to account for its function. He says that its cavity is not connected with any duct and suggests some kind of valvular function for controlling the protrusion of the penis. I cannot agree with this, as such a function would, as far as I know, be unique for Rhabdocoels.

Posterior to the seminal vesicle is another vesicle (pl. 22, v.gr.) which is really the enlarged proximal end of the ejaculatory duct. Haswell (1893) calls it the caecal pouch, Merton (1914) and Bresslau and Reisinger (1933) do not describe it. It is filled with thin-walled ducts containing deeply staining granules and is the granular vesicle found in worms with prostate glands and described by von Graff (1904–08, p. 2274) for Rhabdocoels, resembling particularly that of the Dalyellid *Jensenia angulata.* The seminal vesicle, the granular vesicle and the L-shaped penis (pl. 21, p.) enclosing the ejaculatory

duct, all lie in a more or less straight line with a continuous sheath of circular and longitudinal muscles round all three, the whole being loosely bound to the parallel seminal duct.

An epithelial plasma lines the two vesicles and the penis and is continuous with the atrial epithelium. I could find no nuclei in the plasma, but as it rests on a quite conspicuous basement membrane, the plasma is comparable to the enucleate epithelium lining the pharynx. The plasma varies in thickness in the three different regions. In the seminal vesicle it is fairly wide, but in the granular vesicle and the penis it is extended to fill almost the whole cavity, and through it runs the ducts of the prostate gland (pl. 22, pr″d″). On the outside the plasma rests on the basement membrane, and on the inside it forms the lining of the narrow ejaculatory duct (pl. 22, d.ej.). In the penis the outer plasma contains a firm supporting layer of cutin (pl. 22, cu.) which at the distal end is flexible and is lined with long thin spines (pl. 22, cu.′). No part of the penis can be protruded into the genital atrium since the atrial epithelium is continuous with the epithelial plasma of the penis, but the flexible tip of the penis is able to be evaginated to form an extrovert which in this position has a wide band of spines right round the tip. These spines have the function of firmly attaching the end of the evaginated penis during copulation.

For almost the whole length of the long arm of the penis there extends outside the epithelial plasma a large protoplasmic cell (pl. 22, p.c.) with one large nucleus. Von Graff (1904–08, p. 2287) describes similar cells in Rhabdocoels which lie outside the penis and secrete the cutinous support. This large cell here produces a secretion which is found in lumps between the cell and the cutin, and which stains bright red in Mallory while the cutin stains light orange. The amount of secretion increases towards the distal end of the penis, where it forms a wide band round the outside of the cutin. It is difficult without further experimental work to say how the cutin is formed, but it is quite possible that it is formed by the large cell and that the red secretion is an intermediate stage in its formation.

The prostate glands (pl. 21, pr.) are a series of multicellular, more or less compact glands lying along the sides of the body between the excretory vesicles and the posterior testes. The glands are a uniform grey colour with Mallory, only the nuclei of the cells being deeply stained. The granular secretion, however, stains red and can be traced in strands of ducts running along beside the vasa deferentia. Where the two vasa deferentia join to form the seminal duct, the prostate ducts become more closely packed together and form a solid-looking mass (pl. 22, pr.d.) which ultimately surround the seminal duct as it enters the seminal vesicle (pl. 22, pr.′d.′). The prostate ducts enter the granular vesicle, and their passage through the epithelial plasma has already been described. Their secretion is discharged into the cavity of the ejaculatory duct, where it is mixed with the sperms and may serve to form sperm-packets as in other Rhabdocoels. In none of the previous papers on *Temnocephala* has the granular vesicle and its connection with the prostate gland been properly identified. Merton (1914) and Haswell (1893, p. 125)

both refer to prostate glands and their ducts, but neither seems to have traced out the ducts nor to have identified the granular vesicle as being connected with them, although it is such a regular feature of the Rhabdocoels.

(3) *Female Organs.*

The female organs have more distinctive features than any other part of the reproductive system and have been more recently described by Haswell (1924). They consist of a germarium with a germiduct, vitelline glands with their ducts, a vesicula resorbiens with its duct, three receptacula seminis and the ootype which connects them all with the genital atrium. With the exception of the vitelline glands (pl. 21, vit.g.) which are scattered over the whole dorsal surface, all the female organs are grouped together behind the narrow median part of the intestine and lie on the right side.

The germarium (pl. 21 and 22, gm.) is a compact oval body which can be easily recognised by the very large vacuolated nuclei of its ova (pl. 22, o.n.). The ova are wedge-shaped and are packed firmly together inside a connective tissue capsule. The short germiduct (pl. 22, g.d.) runs forward to enter the ootype, which here also receives the ducts of the three receptacula seminis (pl. 22, r.s.), and the two vitello-ducts (pl. 22, vit.d.). The vitelline glands consist of a series of follicles which are scattered throughout the dorsal parenchyma, particularly in the region of the intestine. The follicular ducts join to form a single vitelline duct on each side.

The vesicula resorbiens (pl. 22, v.r.) is the most anterior of the female organs and lies with its curved border pressed against the posterior wall of the intestine. It is a reservoir of superfluous reproductive material which can be absorbed at intervals into the gut. The contents are mainly yolk granules and secretion of the shell gland which are being produced all the time but are only needed periodically when an egg is being formed. This vesicle was originally called the receptaculum seminis, Weber (1889) and Haswell (1888), and was then thought to be a reservoir for spermatozoa. Haswell (1924) later revised his opinion as to the function of the vesicle in view of the fact that it contained yolk, not spermatozoa, and that Merton (1913) had found other spermatozoa-filled vesicles which were obviously the true receptacula seminis (pl. 22, r.s.), and to Haswell is due the name vesicula resorbiens. Among the Platyhelminths some such method for removing excess products from the female organs is not uncommon. The Laurer canal in the Malacocotylea and the genito-intestinal canal found in some Rhabdocoels, Triclads and Polyclads have the same function.

The anterior part of the ootype receives numerous pear-shaped unicellular shell-glands (pl. 22, sh.g.) with large nuclei. The posterior part is highly specialised to form a thick muscular bulb, the uterus (pl. 22, ut.) lined with hard, sharp teeth in which the egg is held until laid. This very conspicuous bulb is characteristic of *Temnocephala novae-zealandiae* and has no equivalent as far as is known in any other species. The egg is large and when ready to be

laid not only greatly distends the bulb with its hard shell, but displaces all the organs near it, reducing the cavity of the intestine to a slit. Round the atriopore are fine cement-glands (pl. 22, c.g.) for attaching the egg to the Crayfish.

According to Merton (1914) *Temnocephala* is protandrous, ripe spermatozoa having been found in the testes and seminal duct, while the female organs were still not developed. At the same time the receptacula seminis were also very full of spermatozoa which showed that either copulation or self-fertilization had already occurred.

SYSTEMATIC POSITION OF THE SUB-ORDER TEMNOCEPHALIDA.

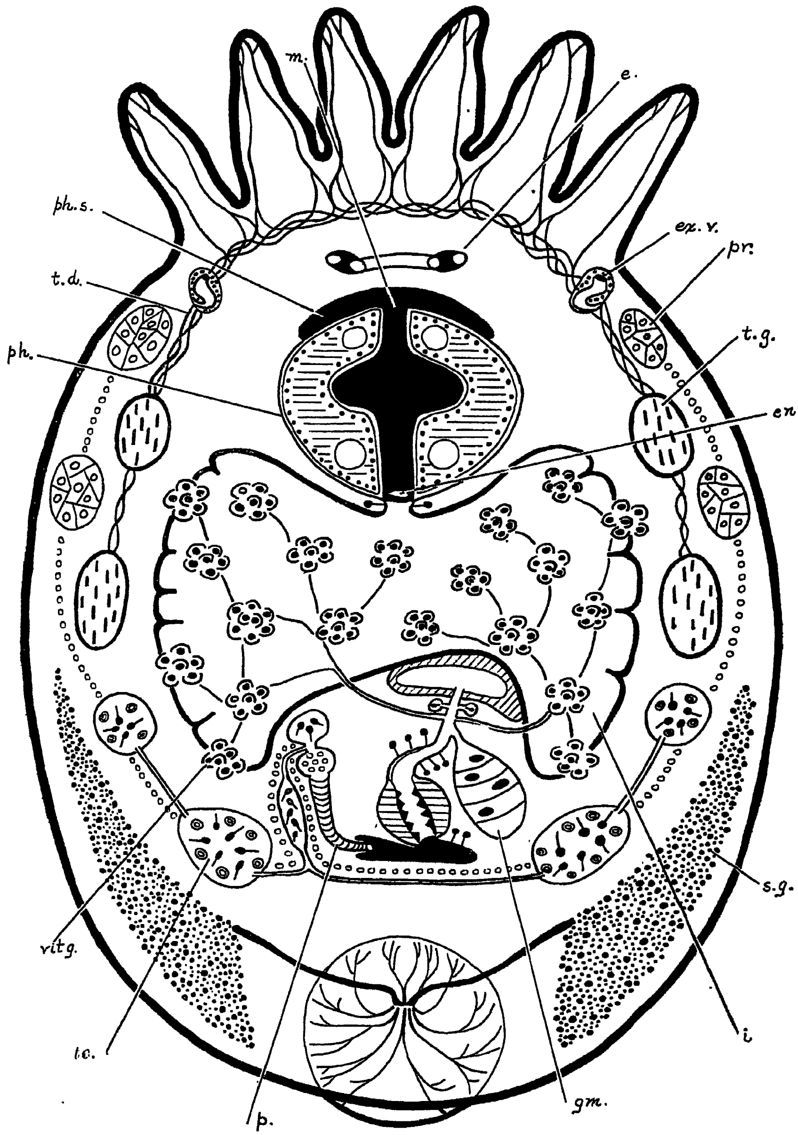
Great interest has always surrounded *Temnocephala* because of the problem of its systematic position. Superficially it appears to have at least some of the characteristic features of more than one class, which has in the past prevented it from remaining securely in any one position and led to the hope that it might prove to be a link between the Turbellaria and the Trematoda.

When first discovered by Gay (1849) it was set down as a Hirudinean, but later on it became a Trematode (Weber 1889 and Braun 1879–93). With a further study of related genera a better knowledge of the group was obtained, and Haswell (1893) and Benham (1901) created a separate class, Temnocephaloidea, of the Phylum Platyhelmia, between the two classes Turbellaria and Trematoda. This new class now contained other genera besides *Temnocephala.*

The Temnocephaloidea, nowadays called Temnocephalida, were first removed from their halfway position and placed in the Turbellaria in the second edition of Claus's *Textbook of Zoology*, edited by von Grobben (1909). Later Mexner (1925), Poche (1925) and Baer (1931) confirmed this, and there they remain at the present time.

Although the more obvious features of the Temnocephalida are ones that we associate with Trematodes—the shape, the sucker, the excretory vesicles and the fact that it lives on a host, these features have one by one been shown not to be exclusively Trematode, and therefore not diagnostic. Suckers are common among the Trematoda, but they may also be present in the Turbellaria. Thus a sucking-organ (according to Bohmig) is present in the acoelous *Convoluta lenseni,* also in the ectoparasitic Rhabdocoel, *Genostoma.* Among the Polyclads the *Cotylea* have a kind of primitive sucker, while among the marine Triclads the Bdellouridae are distinguished by having a sucker at the hind end. Since, therefore, the sucker is found in widely-varied groups of Turbellaria it can be regarded merely as an adaptation to specific circumstances and not as an exclusively Trematode feature, and the suckers of the Temnocephalida must not be used as an argument for classing them with the Trematoda.

The excretory system of the Temnocephalida with its two anterior excretory vesicles is very like that of the Monogenetic



Diagrammatic view of *Temnocephala novae-zealandiae* in a retracted condition from the dorsal surface to show the general arrangement of the organs. For details of the Genital Complex see Pl. 22.

EXPLANATION OF LETTERING.

C.g., cement gland; cu., firm cutin; cu'., flexible cutin with spines which can be everted; d.e.j., ejaculatory duct; d.s., seminal duct filled with spermatozoa; e., eye; en., enterostome leading into the oesophagus with salivary glands on both sides; ex. v., excretory vesicle; g.at., genital atrium; g.d., germiduct; gm., germarium; g.p., genital pore; i., intestine; m., true mouth; o.n., nucleus of ovum; p., penis; p.c., formative cell; ph., pharynx with muscle layers and sphincters; ph.s., pharyngeal sheath; pr., prostate gland; pr.d., massed prostate ducts which at pr'd' surround the seminal duct, and at pr"d" open into the ejaculatory duct; r.m., retractor muscle; r.s., receptaculum seminis; sh.g., shell gland; s.g., sucker gland; t.d., ducts of tentacular gland; te., testis; t.g., tentacular gland; ut., uterus with muscle layers large sphincter and teeth; v.d., vas deferens; v.gr., granular vesicle; vit.d., vitello-duct; vit.g., vitelline gland; v.r., vesicula resorbiens; v.s., seminal vesicle.

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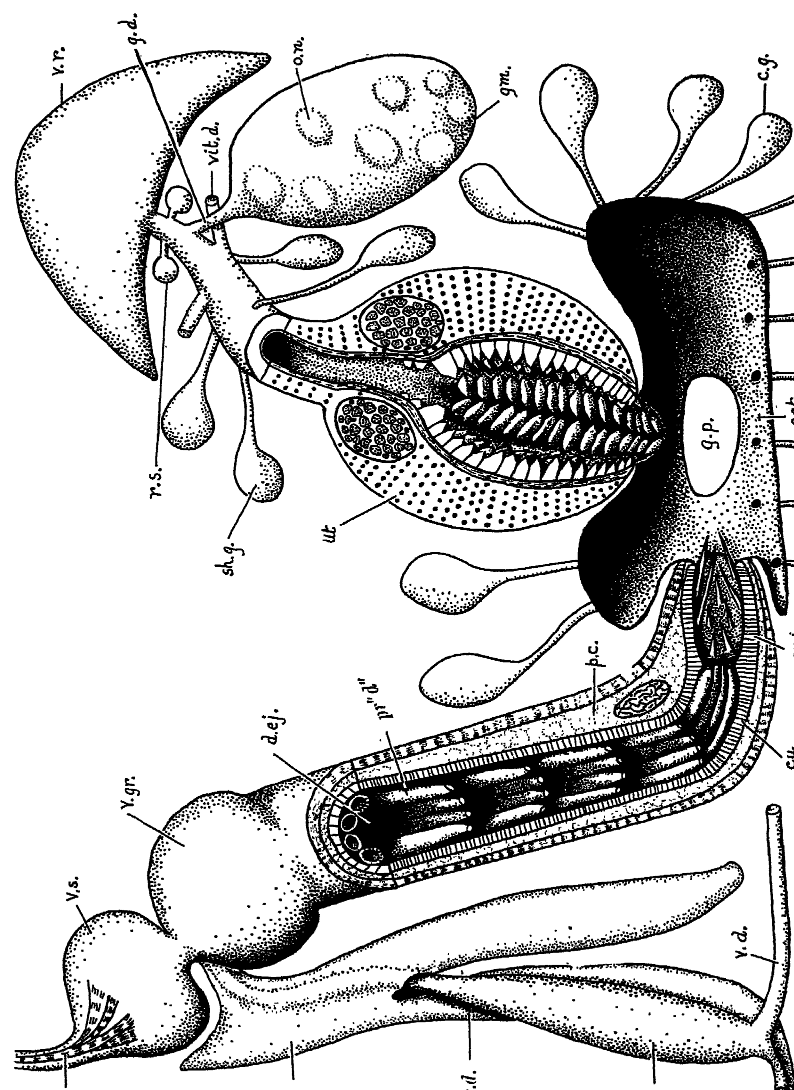
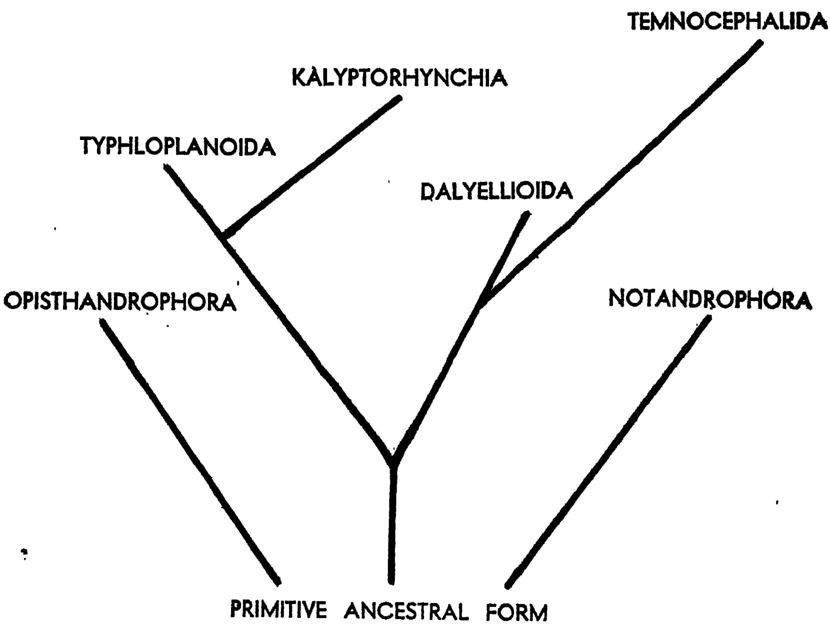


Genital Complex of *Temnocephala novae-zealandiae* in the region of the atrium

Trematodes, but more recent work on the Rhabdocoels shows that in several families of that order similar paired excretory vesicles are present.

As for the Temnocephalida living on hosts, they are epizoic and not ecto-parasitic, indeed the fact that they lead, generally speaking, a non-parasitic mode of life is one reason for removing them from the Trematoda and placing them in the Turbellaria. The Temnocephalida are also separated fundamentally from the Trematoda by the structure of the epithelium, which is ciliated in some forms, and by the possession of rhabdite-forming glands—both Turbellarian characters.

The general anatomy and especially the reproductive organs of the Temnocephalida show a very close relationship to the Turbellarian order Rhabdocoela and it is now universally agreed that they are derived from a free-living Rhabdocoel, though it has not been decided so far which one is its ancestor. According to Bresslau and Reisinger (1933) the Turbellaria are polyphyletic in origin, the Rhabdocoels arising from three separate stems (text-fig.). Of these the Notandropora and the Opisthopora (both forms with ovaries, but differing from each other in the number of main excretory canals) arise on independent stems. The other main stem (forms with germarium and vitellarium) has two principal branches each with one offshoot—one branch the Typhloplanoida with an offshoot Kalyptorhynchia, and the other



Schematic representation of the evolutionary relationship of the sub-orders of the Rhabdocoela. After Bresslau and Reisinger (1933) (1), Fig. 251.

branch the Dalyellioida with an offshoot the Temnocephalida. This branching stem shows many signs of higher organisation and gives rise to a great number and variety of families. Bresslau and Reisinger (1933) believe that the Temnocephalida are closely related to the Dalyellioida, being either directly connected to this sub-order or having evolved parallel to it. This theory has been further strengthened by their inclusion for the first time of *Didymorchis* in the Temnocephalida. This minute animal was discovered by Haswell (1900) in the gill-chamber of *Paranephrops neozealanicus* and was later placed by von Graff (1908) in the Dalyelliidae. However, in its structure and habit *Didymorchis* is typically Temnocephalid except for the absence of tentacles (not a diagnostic feature), and Bresslau and Reisinger consider it to be a Temnocephalid derived from a Dalyellid. This very close connection between *Didymorchis* and the Dalyellioida on the one hand, and between *Didymorchis* and the Temnocephalida on the other points to the fact that the Didymorchidae may be the ancestral group of Temnocephalida and that the three other Temnocephalid families—Scutariellidae, Temnocephalidae and Actinodactylellidae—may have each originated separately from a Didymorchid-like ancestor on the Dalyellid stem of the Rhabdocoela.

Thus the distinction between the Temnocephalida and the Dalyellioida becomes much less marked and the line of separation between the two groups much more difficult to define; indeed, the more one studies the Temnocephalida the more one realises that far from being a unique group separating two important classes it falls into its natural position very close to the Rhabdocoela.

The question now remains whether to include the Temnocephalida in the order Rhabdocoela or to still retain a separate order for them. In the general classification of Vermes at the beginning of Kükenthal, only four orders of Turbellaria are given, the Temnocephalida being included, presumably, in the Rhabdocoela. Bresslau and Reisinger (1933), however, in discussing the phylogeny of the group, consider that the structure and evolution of the Temnocephalida make it still necessary to place them in a separate order of the Turbellaria and not in a sub-order of the Rhabdocoela.

My study of *Temnocephala novae-zealandiae* has further emphasised its close relationship to the Rhabdocoela, particularly to the Dalyellioida. This and the inclusion of the Dalyellid-like *Didymorchis* in the Temnocephalida so reduce the distinctive features of the latter group that there seem to be no characters left which are sufficiently distinct to warrant the formation of a separate order. I therefore have placed *Temnocephala novae-zealandiae* in a sub-order Temnocephalida of the order Rhabdocoela.

Further research on the phylogeny of the Dalyellioida and their relation to the other Rhabdocoel sub-orders may quite possibly show that the line of separation lies not between the Temnocephalida and the Rhabdocoela, but between the Dalyellioida (including the Temnocephalida) and the rest of the Rhabdocoela. This, however, can only be decided after careful study of all the Rhabdocoel sub-orders.

CLASSIFICATION OF THE TEMNOCEPHALIDA.

[From Bresslau and Reisinger (1933), who based their classification on Baer (1931).]

VERMES.

AMERA (unsegmented worms).

Phylum: PLATYHELMINTHES.

Class: TURBELLARIA.

Order: RHABDOCOELA.

Sub-Order: TEMNOCEPHALIDA.

Family 1: Didymorchidae. Temnocephalida without tentacles, and with one pair of testes.—*Didymorchis* Haswell (1900) with 3 species on New Zealand Crayfish.

Family 2: Scutariellidae. Temnocephalida with 2 tentacles and one pair of testes.—Three genera: *Scutariella* Mrázek (1907), 1 sucking-disc, gut divided into two, 1 species on the Southern Atyidae; *Monodiscus* Plate (1914), 1 sucking disc, gut simple, 1 species on the Indian Atyidae; *Caridinicola* Annandale (1912), 2 sucking pits, 1 species on the Indian Atyidae.

Family 3: Temnocephalidae. Temnocephalida with 5 to 12 anterior tentacles and 4–12 testes.—Four genera: *Temnocephala* Blanchard (1849), 5 tentacles, 4 testes, 21 species on South American, Central American, East Indian, Australian, and New Zealand Crabs, Crayfish, and Snails; *Craniocephala* Monticelli (1905), 5 tentacles, 6 testes, 1 species on the New Guinea Crab; *Dactylocephala* Monticelli (1899), 12 tentacles, 12 testes, 1 species on Madagascar Crayfish; *Craspedella* Haswell (1893), 5 tentacles, 10 papillae and 3 transverse lamellae at the posterior part of the body, 4 testes, 1 species on Australian Crayfish.

Family 4: Actinodactylellidae. Temnocephalida with 2 anterior tentacles and 10 at intervals along the body, 4 testes.—One genus: *Actinodactylella* Haswell (1893), with one species on Australian Crayfish.

SUMMARY.

The external and internal features of *Temnocephala novae-zealandiae* are described with reference to previous work on that species and to related forms.

The body-wall is not ciliated, although cilia have been found in other species. In the region of the tentacles, sucker and genital pore, open ducts of glands situated in the parenchyma often at a considerable distance from their exits. The tentacular secretion contains rhabdites.

The nervous system consists of an outer and an inner nerve net with three pairs of longitudinal nerve cords in the inner nerve net and a concentration of nerve cords in front to form the "brain."

In the alimentary canal the true mouth is the opening into the pharynx which is of the pharynx-bulbosus type and may be protruded beyond the so-called mouth. The short oesophagus receives salivary ducts and gland cells are found in the intestinal epithelium. The opening into the oesophagus is the enterostome.

The excretory system is platyhelminth in type with a pair of excretory vesicles at the anterior end. In the walls of the vesicle are numerous flames and fine ducts, and branches of the excretory canals end in flame cells.

The male and female reproductive organs are described. In the male there is a granular vesicle for receiving the ducts of the prostate glands. This is commonly found in Rhabdocoels, but has not previously been described for Temnocephala. The female organs have more distinct features than any other part of the reproductive system. The muscular uterus lined with teeth is unique in *Temnocephala.*

The systematic position of the sub-order Temnocephalida is discussed, and it is shown that the characteristics originally supposed to be exclusively Trematode are also found in Turbellarians and therefore cannot be considered diagnostic features. The Temnocephalida are derived from a free-living Rhabdocoel and are most closely related to the Dalyellids, with which they are either directly connected or to which they have evolved parallel. Bresslau and Reisinger (1933) have enlarged the Temnocephoida so as to include the former Dalyellid *Didymorchis* although it has no tentacles. This further reduces the isolation of the Temnocephaloida and brings them more close to the Dalyellioida. The author places *Temnocephala novae-zealandiae* in the sub-order Temnocephalida of the order Rhabdocoela.

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Some Eocene Mollusca from New Zealand.

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Most of the specimens described below were collected from Hampden Beach during the geological survey of Moeraki Subdivision, North Otago, by Mr D. A. Brown, in 1937-38. Some, also from Hampden, were collected many years ago by Dr P. Marshall, and lodged with the Geological Survey. A full, revised list of the Hampden molluscan faunule will appear in the Geological Survey Bulletin of the district.

The three species from the Opua River, Kakahu, South Canterbury, were collected in 1933 by Dr P. B. Maling, now of London. One of these, *Keilostoma malingi* n.sp. is of outstanding stratigraphic interest, as it provides a direct link with the Eocene of the Paris and London Basins.

All the holotypes of the new species here described are in the N.Z. Geological Survey collection.

NUCULANIDAE.

Nuculana (Pseudoportlandia) tahuia n.sp. (Plate 23; Figs. 1, 2.)

This species is closely related to *N. solenelloides* (Marshall) from Hampden. It differs in being considerably smaller, and in having a relatively greater height compared with the length. This means that the umbos are narrower and more prominent, and the dorsal margins descend more steeply. The posterior margin is narrow and not so abruptly truncated.

Height, 12 mm.; length, 18.2 mm.; inflation (1 valve), 4.5 mm.

Locality: McCullough's Bridge. Tahuian Stage.

When describing his *Sarepta solenelloides*, Marshall (1919, p. 233) stated: "It may be that this is the species recorded by Hutton from these beds under the name *Malletia funiculata*, but his specimens seem to have disappeared, and the name is a *nomen nudum.*" Since *N. solenelloides* is one of the commonest species at Hampden, there is little doubt that this is the shell Hutton included in his *M. funiculata.* The specific name *funiculata,* however, must be recognised, because Hutton gave a reference to Zittel's figure of a Nelson shell (wrongly identified as the Recent *Solenella australis* Q. & G. = *Neilo*). Topotypes from the Cliffs, Nelson, resemble *N. awamoana* Fin., but are only about half the size. The locality, however, does not provide good specimens, so it will be best, until more material is available, to retain *awamoana* as at present, and keep *funiculata* for the Nelson shells and such as closely agree with them.

The following, then, must be added to our Tertiary molluscan fauna:—

Neilo funiculata (Hutton).

1864. *Solenella australis* Quoy and Gaimard, Zittel, *Novara Exped.*, Geol. Theil, 1 Bd., 2 Abt., p. 47, pl. 13, figs. 2a, b (not of Q. and G.).

Holotype: Natural History Museum, Vienna.

Locality: The Cliffs, Nelson. (? Hutchinsonian Stage.)

Nuculana (Jupiteria) hampdenensis n.sp. (Plate 23; Figs. 4, 6.)

Shell resembling *N. leachi* Marw. and probably directly ancestral. It differs in having a more concave posterior dorsal margin, so that the flat escutcheon is not seen when viewed side on. The sculpture is slightly finer than that of *leachi,* but similar concentric grooves due to growth pauses are present.

Height, 3.5 mm.; length, 5 mm.; inflation (1 valve), 1.3 mm.

Locality: Hampden Beach. (Bortonian Stage.)

N. hampdenensis is much closer to *N. leachi* than to *N. parleachi* Laws, which is easily distinguished by its higher posterior beak.

Poroleda antiqua n.sp. (Plate 23; Fig. 5.)

Shell rather small, differing from *lanceolata* in having a more concave and descending posterior dorsal margin, and a slightly more descending anterior dorsal margin, causing the umbo to be more prominent. The ventral margin is not so regularly arcuate, being flattened posteriorly so that the posterior beak is slightly constricted.

Height, 3 mm.; length, 8.5 mm.; inflation (1 valve), 1 mm.

Locality: Hampden Beach. (Bortonian.)

The hinge has not been clearly seen, but it appears to agree with the Recent shell. Iredale separated the Recent shells as *perturbata* from the Pliocene *lanceolata* without adequate grounds. The differences of proportion given by Finlay (1926, p. 445) do not seem to the writer established. Some specimens of *lanceolata* in the Geological Survey collection from Kai Iwi have a length rather more than three times their height. Consequently *perturbata* sinks into the synonymy of *lanceolata.*

Genus OVALEDA Iredale, 1925.

Genotype (original designation): *Sarepta ? tellinaeformis* Hedley, Recent, New South Wales.

Ovaleda constricta n.sp. (Plate 23; Fig. 3.)

Suboval, subequilateral, dorsal margins descending in a regular curve, ventral margin only slightly curved, valves compressed. Surface with extremely fine, spaced, concentric ridges.

Height, 8 mm.; length, 10 mm.; inflation (1 valve), 1.5 mm.

Locality: Hampden Beach. (Bortonian Stage.)

This species is the *Sarepta obolella* (Tate) of Marshall's list (1923 p. 117). From the Australian shell the New Zealand one differs in being larger, stronger and relatively much less inflated. The outlines too, differ markedly, the long, gently curved, ventral margin of *constricta,* contrasting with the strongly convex, ventral margin of *obolella.*

ARCIDAE.

Bathyarca bellatula n.sp. (Plate 23; Figs. 14, 15.)

Shell very small, highly inequilateral beaks at anterior third Hinge straight, nearly as long as the shell. Sculpture of about 30 narrow high radial ribs, with wider, flat interspaces, some of which on the middle and anterior of the disc develop a thin interstitial rib; both ribs and interspaces are crossed by thin, distant concentric ridges, which are not so high as the ribs except near the dorsal margin. Hinge with five anterior and 10 posterior teeth, the distal ones oblique, the medial ones very short and vertical. Shell margin crenulate within.

Height, 2.75 mm.; length, 3.6 mm.; inflation (1 valve), 1.2 mm.

Locality: Hampden Beach. (Bortonian Stage.)

In his valuable revision of the generic divisions of the Arcidae, P. W. Reinhart (1935, p. 36) has correctly pointed out that the two New Zealand fossils *Microcucullaea crenulifera* and *M. pectinata* Marwick, 1931, are closer to *Bathyarca* than to *Microcucullaea*. His placing of *Microcucullaea* as related to *Bathyarca* rather than to *Cucullaea* is also justified by a general consideration of the hinges, sculpture and shape of these small shells.

In his table of distinguishing characters, Reinhart gives *Bathyarca* as having a smooth margin, but this seems to be a variable character, as regards the present scope of the genus. A great range of differences in hinge teeth is also shown, indeed it seems certain that some very distantly related species are at present included. Reinhart stated that he had not found a definite record of *Bathyarca* earlier than the Oligocene, apparently disregarding Cossman's suggestion, cited by Woodring (1925, p. 53), that *A. lissa* Bayan from the Parisian Eocene is a *Bathyarca*. This absence or rarity of the genus in the Eocene gives added interest to *B. bellatula*.

PECTINIDAE.

Lentipecten parki n.sp. (Plate 23; Figs. 7, 10, 13.)

Shell fairly large, almost equilateral and equivalve except for the ears. Dorsal margins slightly concave, apical angle increasing from about 110° to about 125°. Surface smooth, but having extremely fine, regular, concentric grooves, about 12 per mm. Ears subequal, relatively very long, those of the left valve with a remarkably straight dorsal margin and almost rectangular corners, those of the right valve with a strongly but irregularly serrate dorsal margin. Right anterior ear with a moderately deep byssal notch which, however, does not form a radial groove or ridge. Both ears of the right valve set on a plane oblique to that of the disc and separated from it by a step or ramp which gets rapidly broader distally. Internally, the hinge-margin is narrow, and quite intersected by the resiliary pit.

Height, 55 mm.; length, 57 mm.; inflation (1 valve), 8 mm.

Localities: Hampden Beach (type); G.S. 2572, Waihao Downs; G.S. 164, Greensands, Kakahu (Bortonian Stage); G.S. 2873, Ten Mile, Greymouth, near top of Island Sandstone (? Tahuian).

This shell is, of course, very like the widespread Miocene *L. hochstetteri* (Zitt.), and has been so identified (under the synonym *P. huttoni* Park) in most lists of Hampden mollusca. The two species are easily distinguished by their ears. In the left valve, the ears of *hochstetteri* (Plate 23, fig. 12) have a much shorter dorsal margin having, at its extremities, obtuse angles of about 120°. The long, straight dorsal margin of the ears of *L. parki* (Plate 23, fig. 13) forms with the anterior and posterior vertical margins an approximate right angle. In the ears of the right valve the dorsal margin is straighter and the distal angles are rounded and obtuse in *hochstetteri* (Plate 23, fig. 9), but they are sharp and subrectangular in *parki* (Plate 23, figs. 7, 10). Further, the bysal notch of *parki* is considerably deeper, but the shallow sinus of *hochstetteri* forms a low radial bulge.

If the ears are missing difficulty may be met in identifying the disc of *parki* as distinct from *hochstetteri*, but the very fine regular concentric grooves are better developed in *parki*. Another item for distinguishing *parki* is the well defined step or ramp on the right valve, separating the ear from the disc.

The holotype of *L. waihaoensis* consists of a fairly complete, ribbed left valve and a smooth right valve with much damaged ears. These were collected by J. A. Thomson, together, and appeared to belong to one individual. If the relationship of the valves is as supposed, then *parki* must be closely related to *waihaoensis*, because their right valves are indistinguishable. No ribbed left valves have been found at Hampden, though smooth ones are not uncommon; but at Waihao Downs both smooth and ribbed left valves occur. Further, there are differences in the strength of the ribs. It may be that a gradation exists at Waihao between the smooth and the ribbed, but more material is required to throw light on this question. The absence of any ribbing on the Hampden shells justifies their systematic recognition.

VENERIDAE.

Marama (Hina) vaga Marwick. (Plate 24; Figs. 23, 24.)

1927. *Trans. N.Z. Inst.*, vol. 57, p. 605.

When this species was described originally, figures were promised for the following year. Somehow, they have always escaped publication, so the writer is glad of this chance to carry out the promise, even if belatedly.

Locality: McCulloughs Bridge. (Tahuian Stage.)

VERTICORDIIDAE.

? Verticordia neozelanica (Suter).

1873. *Trigonia pectinata* Lamk.: Hutton, *Cat. Tert. Moll. and Ech.* N.Z., p. 27.

1914. Suspend: Suter, *N.Z. Geol. Surv. Pal. Bull.* 2, p. 38.

1915. *Trigonia neozelanica* Suter, *N.Z. Geol. Surv. Pal. Bull.* 3, p. 50, pl. 5, fig. 3.

Hutton apparently identified his single specimen with the Recent Australian *Trigonia* largely because the shell is pearly. No further specimens have been collected. The exterior sculpture was concealed by matrix and the umbo and hinge, as noted by Suter, are missing. When the exterior had been laid bare, Suter gave the specimen a specific name, following Hutton's generic placing without comment. He considered the shell to be a left valve, thus treating the beaks as opisthogyrous, as they should be if the shell is a Trigonid. However, the right hand side of the disc shows no modified posterior area such as is invariably present in *Trigonia*, but the left side has a well marked radial depression, extending from the umbo to the ventral margin. This so closely resembles the posterior depression characteristic of many pelecypods that we are almost certainly dealing with the right valve of a prosogyrous shell. Certainly, *Trigonia* is ruled out, but until further evidence is available, the real affinities are uncertain. The pearly shell, cordate shape, and regular, strong, radial ribs suggest the Verticordiidae, though the size is much greater than usual.

Locality: Hampden Beach. (Bortonian Stage.)

Verticordia densicostata (Marshall).

1919. *Trigonia densicostata*: Marshall, *Trans. N.Z. Inst.*, vol. 51, p. 234, pl. 16, fig. 1.
1923. *Verticordia densicostata*: Marshall, *Trans. N.Z. Inst.*, vol. 54, p. 117.

This species has already been transferred by its proposer, at the suggestion of Cossmann, from *Trigonia*, but as this appears only in a list, it is liable to be overlooked. Here, again, we have to deal with a single specimen, so poorly preserved that even the family affinities are uncertain. It was placed under *Trigonia* "merely in order that it may be possible to refer to it by name. . . . In the meantime, it may be said that the species does not belong to any other genus of Tertiary or Recent mollusca hitherto found in New Zealand."

The sculpture of *densicostata* is similar to that of the preceding *V. neozelanica*, but the shape does not agree so closely. Since this may be due to distortion during consolidation or movement of the beds, and since both specimens come from the same locality, it is conceivable that only one species is concerned. More specimens, however, are needed to show the true affinities of these two shells. Only one posterior fragment of what is probably *densicostata* was collected by the writer.

Locality: Hampden Beach. (Bortonian Stage.)

Genus KURINUIA nov.

(From the Kurinui Stream, which flows through Hampden.)

Genotype: *Trigonia areolata* Marshall. Bortonian (Middle Eocene).

Shell pearly, of moderate size, cordate, beaks strongly prosogyrous. Sculpture: middle and anterior of disc bearing strong, rounded, radial ribs, with narrow interstices; posterior area not excavated, but with a wide, ribless space crossed by regular, low, concentric ridges, sharply defined in front by a deep furrow, and bounded posteriorly by a low, angled rib near the dorsal margin. Right hinge bearing a strong, smooth, curved, pointed, cardinal tooth immediately behind the umbo, also a strong lamellate posterior lateral. Valve margins coarsely crenate.

Kurinuia areolata (Marshall). (Plate 23; Figs. 8, 11.)

1919. *Trigonia densicostata*: Marshall, *Trans. N.Z. Inst.*, vol. 51, p. 234, pl. 15, fig. 1; pl. 17, fig. 1.

Although the only two specimens available for examination are somewhat broken below the beak, the damage is not so serious as to conceal the essential characters of the hinge. Dr Marshall noted the smooth cardinal tooth and the prosogyrous beaks, but considered these to be a possible *Trigonid* development. The single smooth cardinal in the right valve is placed on a definite hinge plate and is curved forward and upward to a point rather like *Corbula*. There is no sign of external ligamental nymphs such as are present in the Trigoniidae, the ligamental groove being internal and running between the posterior lateral tooth and the dorsal margin. Further, the lunule is deeply excavated and the shell is of cordate shape.

All these characters show clearly that the shell is not a *Trigonia* but is related to *Verticordia*, from which, however, it differs in being much larger and in having a different kind of sculpture. The hinge resembles that of *Haliris* Dall, 1886, type *Verticordia fischeriana* Dall,

and also that of *Setaliris* Iredale, 1930, type *Verticordia setosa* Hedley; but the strongly differentiated posterior area of *areolata* is quite peculiar. Agreement may be closer with *Euciroa* Dall, 1881, type *V. elegantissima* Dall which has weak ribbing on the posterior area, and is of large size, but which has fine, spiny sculpture. Further, the left hinge figured by Dall (*Mus. Comp. Zool.*, vol. 12, pl. 2, fig. 1b) is evidently not the complement of the right hinge of *areolata*.

Incidentally, there does not seem to be much difference between *Setaliris* and *Haliris*. Iredale (1930, p. 406) gave no reason for his proposal, and as far as one can judge from the figures, *setosa* may well be closely related to *fischeriana*. Further, the "Aberrant occurrence" of Hedley's species, mentioned by Iredale (1930, p. 388) presumably referring to Hedley's remarks about the genus *Verticordia* characterising deeper water, does not apply to the group *Haliris*, for the type, *fischeriana*, occurs at much the same depth as the New Zealand *setosa*, namely, about 100 fathoms.

CALLIOSTOMATIDAE.

Maurea (Mucrinops) barbara n.sp. (Plate 24; Fig. 16.)

Shell rather small for the group, conic, sides straight, body-whorl bluntly angled at the periphery, base flattened, concave. Sculpture: spire-whorls with five strongly moniliform spirals differing somewhat in strength, the lowest close to the suture and weak. The highest spiral bears about 20 beads per whorl, and the others from 25 to 30. Base with 8 relatively broad and low spirals separated by wider interspaces, the outer three bearing a weak secondary thread. Growth lines strongly marked.

Height, 14 mm.; diameter, 13 mm.

Locality: Opua River, a quarter mile below Gorge Bridge, Kakahu (Bortonian), P. B. Maling coll.

This species is characterised by its very coarse sculpture.

RISSOINIDAE.

Genus KEILOSTOMA Deshayes.

1850. *Traité élém. Conch., Atlas*, p. 46. = *Paryphostoma* Bayan, 1873.

Genotype (by monotypy): *Melania marginata* Lamk. (= *Bulimus turricula* Brug.) Lutetian, Paris Basin.

Keilostoma malingi n.sp. (Plate 24; Figs. 17, 18.)

Shell rather small, turriculate, imperforate. Protoconch not preserved on any of the specimens. Whorls with almost straight sides, suture plainly but not strongly marked, faintly staging the spire. Sculpture of flat, imbricate bands also faintly staging the spire, six on early whorls increasing to seven on later ones; body-whorl with 10 or 11 broad bands and a few narrow ones anteriorly. Aperture, entire, narrowly channelled posteriorly, broadly subtruncate anteriorly; peristome continuous. Outer lip gently convex, slightly reflexed and thickly callused, callus growing forward considerably. Inner lip thickly padded.

Height (incomplete), 12.5 mm.; diameter, 4.3 mm.

Locality: Opua River, a quarter mile below Gorge Bridge, Kakahu (Bortonian), collected by P. B. Maling.

K. malingi rather closely resembles the French and English Eocene *K. minus* (Desh.) in size, shape and sculpture, differing in having a straighter outline, slightly broader spirals, weaker growth lines and a greater spread of callus on the base. It agrees much more closely with *minus* than with any of the three Cretaceous Indian species, *substriatum, subulatum,* and *politum.* It is probably, therefore, directly related to the European species and so forms a useful link in connecting the Bortonian stage with the Eocene.

Cox (1931, p. 47) has described a *Keilostoma subturricula* from the Laki (Eocene) of India, but it was formerly identified as the European *turricula* Brug., and is not so close to *malingi* as is *minus.*

The generic term *Paryphostoma* was used for this shell by Finlay and Marwick (1940, p. 87), following Cossmann (1921, p. 70) who considered *Keilostoma* preoccupied by *Chilostoma* Fitz., 1833. Sherborn also cites a *Cheilostoma* Diesing, 1850, that is even closer in form, but may not be earlier. On reconsideration, the writer has decided, in view of the vagueness of the rules on this subject, to use the older name, *Keilostoma.*

NATICIDAE.

Friginatica haasti (Marwick). (Plate 25; Fig. 31.)

1924. *Natica (Carinacca) haasti* Marw., *Trans. N.Z. Inst.*, vol. 55, p. 554, pl. 56, fig. 8.

The finding of a fine large specimen of this rather rare species, measuring 13 mm. by 13 mm. is worth recording. Study of this shell indicates that the generic position should be changed from *Carinacca* to *Friginatica.* Although the basal limb resembles that of *Carinacca,* the globular shape, the deeply impressed, almost channelled suture, and the shape and disposition of the parietal callus all suggest relationship to *Friginatica.*

CASSIDIDAE.

Galeodea geniculosa n.sp. (Plate 24; Fig. 25.)

Shell similar to the Miocene *G. apodemetes* Marw. and probably directly ancestral; differing in having a concave, transverse shoulder. Consequently the shoulder tubercles are higher set. The sides of the spire-whorls are concave and more sloping than those of *apodemetes,* which are almost cylindrical. Sculpture of body-whorl almost the same in the two species, except that on the new species the primary spirals are better defined from the secondary and tertiary ones in the interspaces, especially on the base. An infra-sutural band is present, puckered by strong growth ridges, and resembling that of *Euspinacassis.* The parietal and columellar callus is closely applied to the body at its outer edge and does not project as in the Miocene descendant; also it is more wrinkled within.

Height, 39 mm.; diameter, 27 mm.

Locality: Hampden. Bortonian Stage.

All of the specimens are incomplete and distorted, the true diameter was less than this by several millimeters.

FICIDAE.

Priscoficus alectodens n.sp. (Plate 25; Figs 33, 34.)

Shell of moderate size, thin and fragile. Spire-whorls staged, with a wide, slightly concave shoulder and short, slightly concave, sloping sides. Body-whorl contracting rapidly on the base to a long, narrow canal which is not notched anteriorly. Sculpture: the spire-whorls bear sharp tubercles on the shoulder-angle, about 20 on each of the early whorls but decreasing on later ones to 18, 16 or even fewer. Body-whorl having three well-spaced rows of strong, sharp, laterally extended tubercles, the middle row forming the periphery. The whole surface marked by spiral cords with wide, flat interspaces, several times the width of the cords. The spirals differ greatly in strength, some, especially each one on the tubercled bands, being very strong, others can scarcely be seen. Between the suture and the top row of tubercles there are four spirals on earlier whorls, but the number on the adult is uncertain. Between the top and middle tubercled bands are four spirals on the immature specimen and seven on the larger one, the top one and the lowest three being much weaker than the others. Between the middle and the bottom tubercled band are three strong cords, with a weak to faint thread in all interspaces except the second lowest. Between the lowest band and the anterior end of the shell are some 29 spirals, the top six alternating markedly in strength; the next four, that is, those about the junction of the base and neck, are all strong; and the next 10 on the neck alternate in strength. Anteriorly are about nine, closely placed, wavy threads.

Height, 47 mm.; diameter, 25 mm. (body fragment, holotype).

The dimensions of a complete adult probably about 65 x 35 mm.

Locality: Hampden Beach. (Bortonian Stage.)

This is probably the species from Kakahu listed by Finlay and Marwick (1937, p. 119, pl. 16, fig. 18) as *Priscoficus* n.sp. A. Apology may be due for naming such poor material, but the sculpture of the body-whorl is clearly shown and is quite distinctive.

EPITONIIDAE.

Cirsotrema kuriensis n.sp. (Plate 24; Fig. 21.)

Shell moderate to small for the genus. Sculpture consists of very strong, high axial ribs, 10 per whorl, separated by considerably narrower, flat interspaces, except on the early whorls where the ribs are narrower than the interspaces. Both ribs and interspaces are crossed by seven strong, spaced, spiral cords which are weaker, however in the interspaces. The spiral interspaces and the backs of the ribs bear numerous, close, spiral threads about 4 per interspace. The crests of the ribs, between the spiral cords have many close, sharp, vertical growth-ridges.

Height, 28 mm.; diameter, 12 mm.

Locality: Hampden Beach. (Bortonian Stage.)

This species combines features of both *lyrata* Zittel and *caelicola* Finlay. The thick ribs surpass those of *caelicola* but are about the same in number, and the spiral cords resemble those of *lyrata*, under which name the shell has generally appeared in Hampden lists.

EULIMIDAE.

Niso basiglobosa n.sp. (Plate 24; Figs. 19, 20.)

Shell of moderate size, narrowly conic. Protoconch eroded in the single specimen. Whorls 12, height of each about three-eighths diameter, sides flat. Surface somewhat pitted by weathering, growth lines weak, a number of oblique, slightly concave growth pauses well defined. Suture inconspicuous. Body-whorl slightly over one-third total shell height, regularly rounded on the periphery. Umbilicus moderately large, its walls curved and merging gradually into the base without any ridge. Aperture relatively short, with just a suggestion of an anterior beak. Outer and inner lips thin, parietal wall without callus.

Height: 17 mm.; diameter, 6.5 mm.

Locality: Opua River, a quarter mile below Gorge Bridge, Kakahu (Bortonian), P. B. Maling coll.

The absence of a ridge bounding the umbilicus and the rounded periphery show that this shell is off the main line of *Niso* descent. Cossman and Peyrot's *N. degrangei* from the Helvetian of Aquitaine is similar though it has a sub-angulate periphery, straighter umbilical walls and, therefore, a better defined beak. *N. angusta* Desh. from the Paris Basin Eocene has a rounded periphery but a smaller umbilicus. Cossman and Peyrot (1917, p. 286) stated moreover that the protoconch of *degrangei* has a heterostrophic nucleus. This confirms the evidence of the other characters that this species does not belong to *Niso* restricted, and perhaps not to *Niso* even in a wide sense. It should at least be subgenerically separated. Whether *angusta* or the new species belongs to this group or to another one cannot be decided until the protoconchs are known.

FASCIOLARIIDAE.

Zexilia hampdenensis n.sp. (Plate 24; Fig. 22.)

Shell larger than *Z. waihaoensis* and having somewhat higher, less convex whorls. The ribs are narrow, having rather a sharp ridge and so being triangular in cross section; they are also more numerous, the last whorl having 28, and the penultimate 20. As in *waihaoensis*, the spiral cords number six per whorl, with a seventh appearing in the lower suture. They are strong, but relatively narrow, with wide interspaces, and are raised into tubercles where they cross the axials.

From *Z. tenuilirata* Laws and *Z. submarginata* Laws, *Z. hampdenensis* is easily separated by its more convex whorls, stronger spirals, and differently curved axials.

Height, 22mm.; diameter, 7 mm. (spire only). Paratype, 33 x 7 mm.

Locality: Hampden Beach. (Bortonian Stage.)

Fascioplex neozelanica (Suter). (Plate 25; Fig. 28.)

1934. Marwick, *Proc. Mal. Soc.*, vol. 21, p. 16, pl. 1, figs. 6, 8.

A single, rather distorted, but otherwise good specimen from Hampden Beach (Bortonian) probably should be included in our conception of this species, or as G. Simpson (1940, p. 413) would express it, " should be included in the hypodigm " of *F. neozelanica.*

It differs from any previous members of this species seen by the writer in having only obsolete axials on the body-whorl, and so presenting a strong ficoid appearance externally.

Fascioplex browni n.sp. (Plate 25; Fig. 30.)

Shell fusiform, turreted, imperforate; spire two-thirds height of aperture and canal. Whorls strongly angled, base contracting rather quickly to (apparently) a straight canal. Sculpture: spire whorls with nine, body whorl with ten strong, vertically compressed, sharp tubercles on the shoulder angle. Although compressed vertically, the tubercles are set on axials of moderate strength but somewhat irregular definition. Shoulder with two weak spiral threads also with traces of an interstitial and of other spirals. Below the shoulder are six strong, distant imbricate cords, mostly with two or three weak, well spaced secondary spiral threads. The whole surface bears strong laciniate, sinuous growth-ridges, about one per millimeter, quite trophonid in appearance. Sutures appressed, high up on the preceeding whorl. Columella having at its base two strong, oblique plaits, the lower somewhat stronger, between them a well defined channel.

Height, 35 mm.; diameter, 24 mm.

Locality: G. S. 1988. Greensands, in abandoned rail cutting, Waihao Downs.

This species resembles *F. liraecostata* in sculpture but is easily distinguished by the high, staged spire. Also the canal, though broken, appears to have been straight, and there is no sign of any fasciole.

?Fascioplex n.sp. (Plate 25; Fig. 32.)

A fragment of the body whorl of a shell shows in section a spiny sculpture, in part at least, set on a muriciform varix. The columella has, at its junction with the long, slightly curved canal, two strong plaits, the lower somewhat stronger and the two forming a narrow, deep, oblique channel. These columellar folds agree closely with those of *Fascioplex* but the canal appears to be much longer and narrower. The sculpture, as far as can be seen, suggests the Muricidae. The shell is apparently rare, as only the one fragment has been seen; and a certain placing of it must wait for further specimens. The species previously described, *Fascioplex browni,* forms, with its sharply raised trophonid ridges a kind of link between this peculiar Muriciform shell and *Fascioplex.*

Falsicolus altus (Marshall). (Plate 25; Fig. 27.)

1919. *Fusinus altus* Marsh. *Trans. N.Z. Inst.*, vol. 51, p. 229, pl. 16, fig. 5.

Judged from more than a dozen fragmentary specimens, *F. altus* appears to differ consistently from *bensoni* Allan which was synonymised with it by Finlay (1930, p. 260). The ribs are more numerous in *altus,* being from 11 to 12 per whorl, against the nine of *bensoni.* Except on the last whorl or so, the ribs of *altus* are not tuberculed as in *bensoni,* so that the spire whorls are convex instead of angled. Certainly the species are closely related, and *F. solidus* (Suter) is perhaps intermediate between the two. Of course the whole question of what is a species immediately arises, but it cannot be adequately discussed here. However, it may be stated that the species envisaged is a convenient group of individuals sufficiently interrelated to maintain a reasonably uniform set of genetic characters.

Owing to the lack of good specimens, *F. altus* has not been adequately figured. The figure here supplied still leaves much to be desired, but it will serve to differentiate *altus* from *bensoni*.

Locality: Hampden Beach. (Bortonian Stage.)

MITRIDAE.

Genus COMPSOMITRA nov.

Genotype: *Compsomitra incisa* n.sp. Bortonian (Middle Eocene).

Shell rather small, fusiform, spire higher than aperture. Protoconch of about two whorls, with a large, bulbous apex. Whorls convex, body contracted quickly on the base to a long, straight neck without a fasciole. Sculpture of numerous, strong axial ribs, triangular in cross section, not defined from the interstices. The whole surface bears regular spiral grooves, separating flat cords on the sides of the whorls, but round cords on the base. Columella with three strong folds, and a fourth very weak one anteriorly.

The Mitrids have had about 50 subdivisions proposed, so that one hesitates to add to the number. However, as far as the writer can determine, none of the proposed groups appears to be at all close to the Hampden shell, consequently a new division has to be set up for it.

Compsomitra is perhaps nearest related to some of the species at present included in *Costellaria* Swainson, such as *borsoni* and *recticostellata* Bellardi from the Miocene of the Vienna Basin. The type of *Costellaria, M. rigida* Swainson, is, however, a different-looking shell. It has a long, sub-cylindrical body, with a very short canal, strongly notched and fascioled. Iredale (1929, p. 346) has indicated the need for further study in the group. His *Mitropifex* shows some points of agreement with *Compsomitra* in sculpture and convexity of whorls, but the high spire and twisted canal are different.

Compsomitra incisa n.sp. (Plate 25; Fig. 29.)

The axials number about 21 per whorl, they are strongly arched, so that the outer lip had a sigmoid outline. The penultimate whorl has 10 flat spiral threads, the posterior thread being twice as broad as the others and so forming an infrasutural border. The outer lip of the single specimen has been broken off, but there is no sign of internal lirae. The growth lines indicate that there was no anterior sinus to the canal.

Height, 16 mm.; diameter, 6.5 mm.

Locality: Hampden Beach. (Bortonian Stage.)

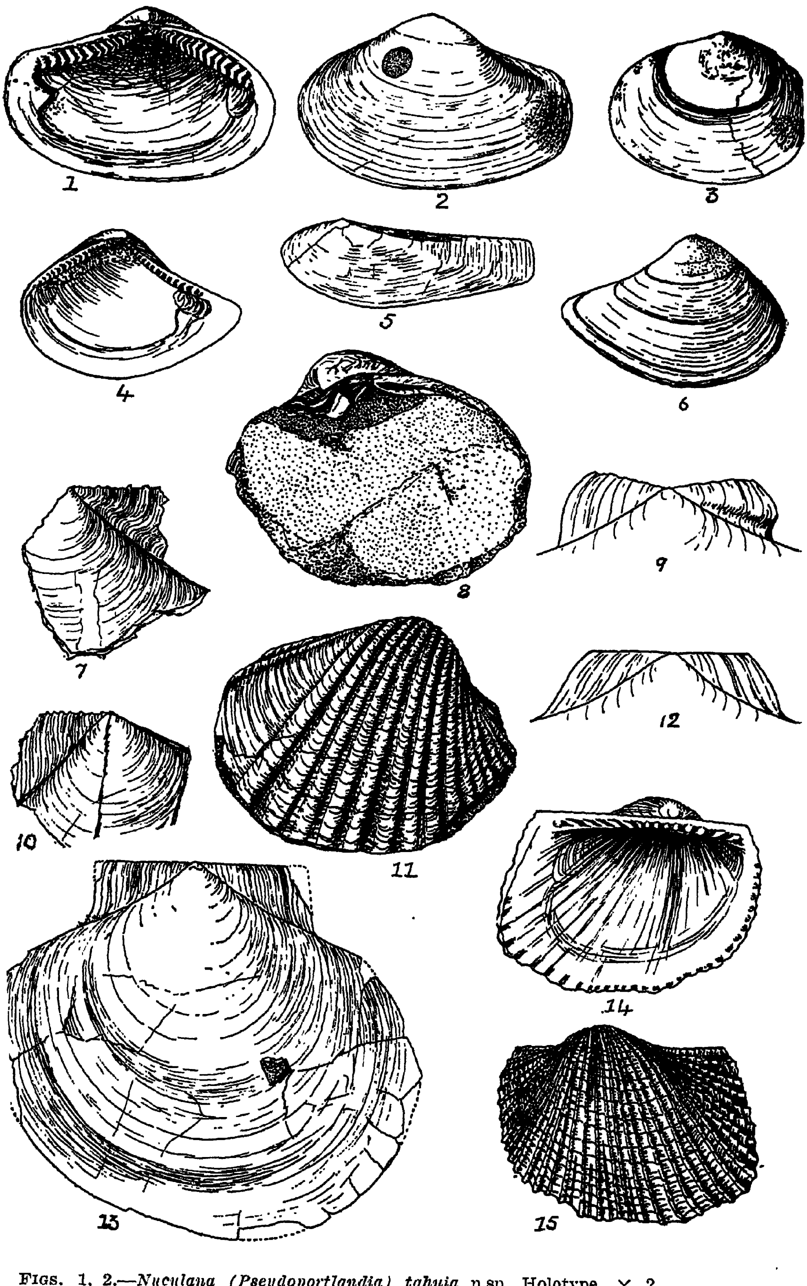
COLUMBARIIDAE.

Coluzea aff. **climacota** (Suter).

1917. *Fusinus climacotus* Suter, *N.Z.G.S.*, *Pal. Bull.* No. 5, p. 21, pl. 3, fig. 12.

1926. *Coluzea*, Finlay, *Trans. N.Z. Inst.*, vol. 57, p. 407.

A large spire (26 mm.) from Hampden Beach (Bortonian) has only two, instead of three, primary spirals on the shoulder, with a weak interstitial. A small, imperfect specimen (22 mm.) from the same place has three weak spirals on the shoulder. The material is not good enough to make sure, but it suggests that the Hampden form is separable from *climacota* s.str.



FIGS. 1, 2.—*Nuculana (Pseudoportlandia) tahuia* n.sp. Holotype, × 2.
FIG. 3.—*Ovaleda constricta* n.sp. Holotype, × 2½.
FIGS. 4, 6.—*Nuculana (Jupiteria) hampdenensis* n.sp. Holotype, × 6.
FIG. 5.—*Poroleda antiqua* n.sp. Holotype, × 4.
FIGS. 7, 10.—*Lentipecten parki* n.sp. Paratypes, right valves, × 1.
FIGS. 8, 11.—*Kurinuia areolata* (Marsh.) n.gen. Hampden, × 2.
FIGS. 9, 12.—*Lentipecten hochstetteri* (Zitt.) Ears of right and left valves, × 1.
FIG. 13.—*Lentipecten parki* n.sp. Holotype, × 1.
FIGS. 14, 15.—*Bathyarca bellatula* [illegible]

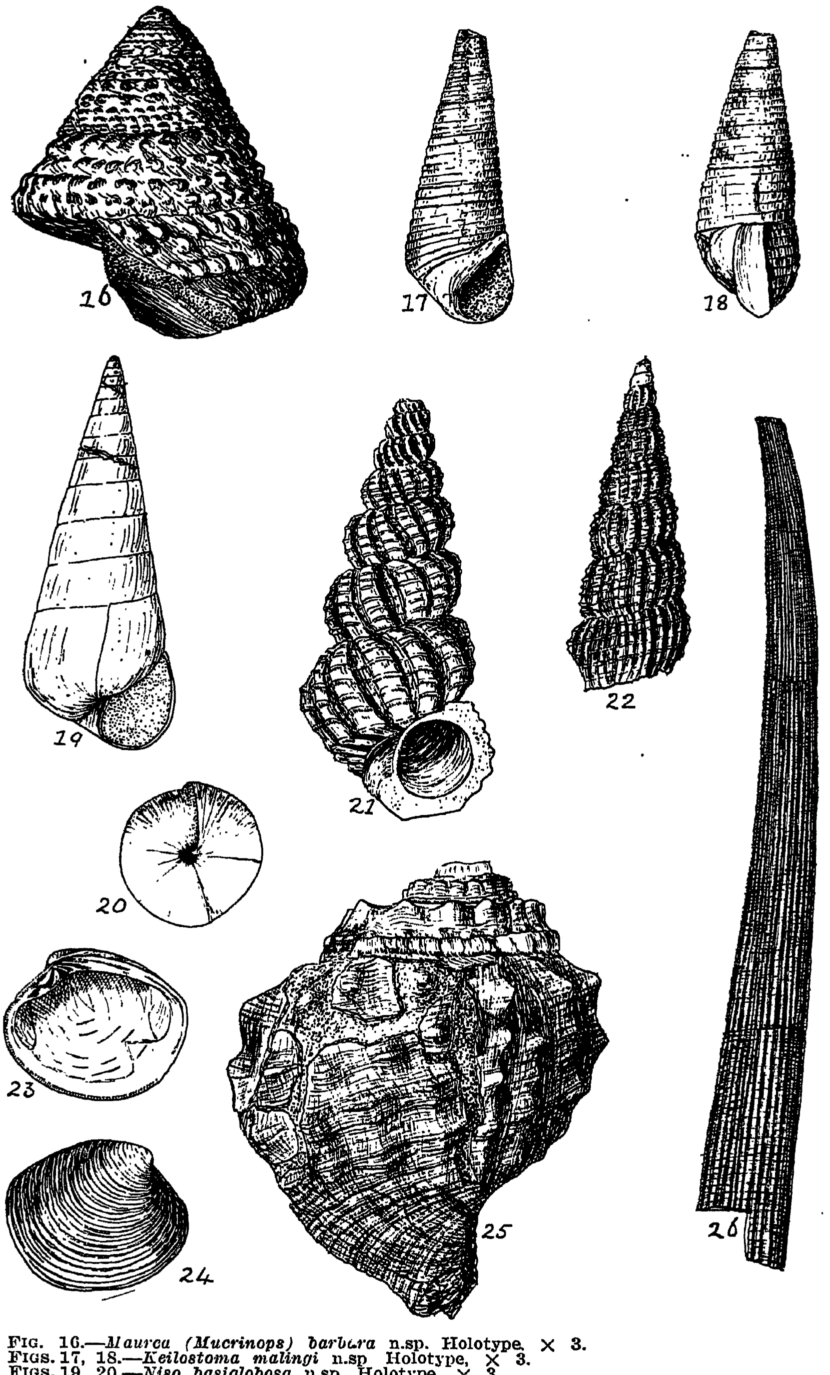


FIG. 16.—*Maurea (Mucrinops) barbara* n.sp. Holotype, × 3.
FIGS. 17, 18.—*Keilostoma malingi* n.sp. Holotype, × 3.
FIGS. 19, 20.—*Niso basiglobosa* n.sp. Holotype, × 3.
FIG. 21.—*Cirsotrema kuriensis* n.sp. Holotype, × 2.
FIG. 22.—*Zexilia hampdenensis* n.sp. Holotype, × 2.
FIGS. 23, 24.—*Marama (Hina) vaga* Marw. Holotype, × 1.
FIG. 25.—*Galeodea geniculosa* n.sp. Holotype, × 1½.
FIG. 26.—*Dentalium centenniale* n.sp. Holotype, 1½.

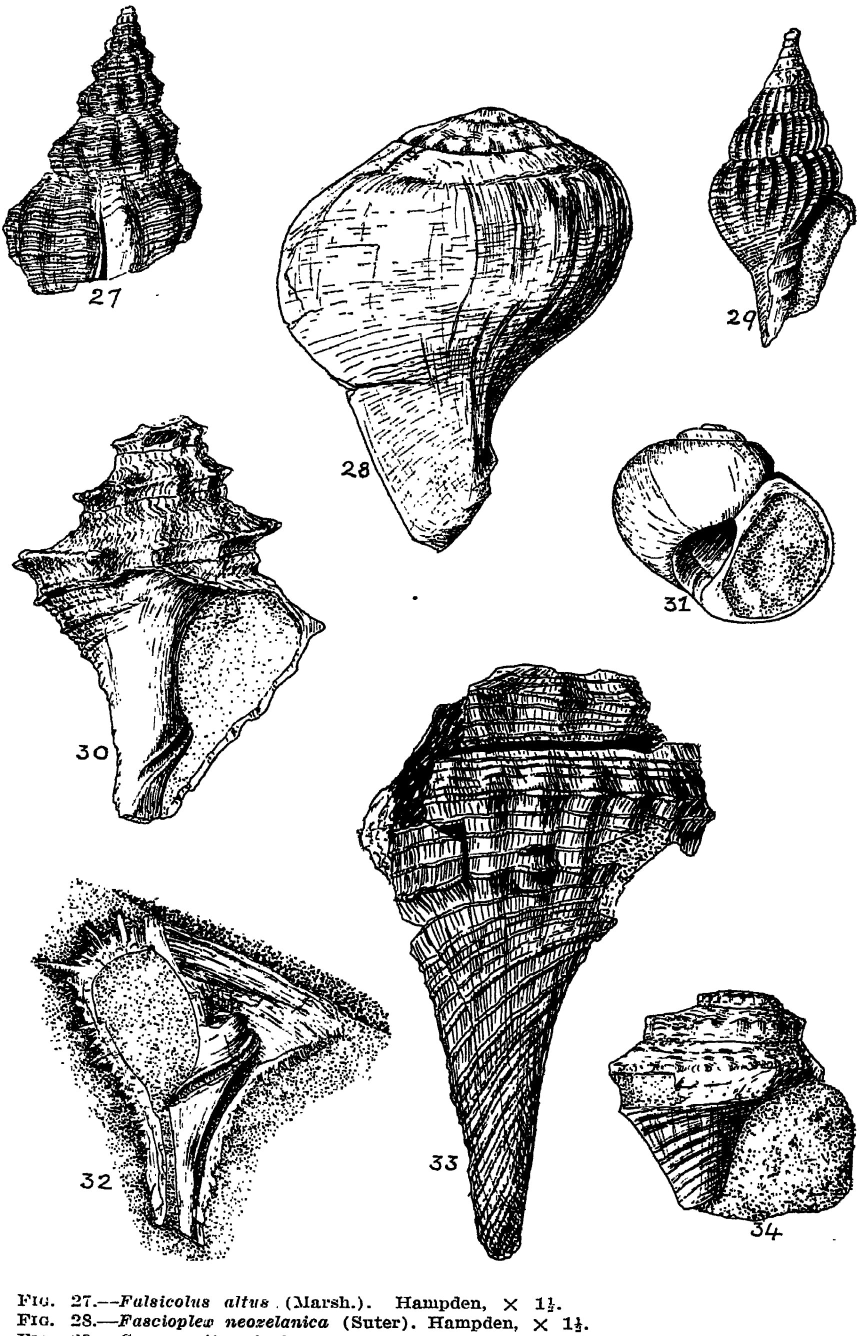


FIG. 27.—*Falsicolus altus* (Marsh.). Hampden, × 1½.
FIG. 28.—*Fascioplex neozelanica* (Suter). Hampden, × 1½.
FIG. 29.—*Compsomitra incisa* n.gen., n.sp. Holotype, × 2½.
FIG. 30.—*Fascioplex browni* n.sp. Holotype. × 1½.
FIG. 31.—*Friginatica haasti* (Marw.). Hampden, × 2.
FIG. 32.—*Fascioplex* n.sp. Hampden, showing Muricoid sculpture, × 1.
FIGS. 33, 34.—*Priscoficus alectodens* n.sp Holotype and paratype, × 1½.

Dentalium centenniale n.sp. (Plate 24; Fig. 26.)

Shell of moderate size and thickness, rather slender, tapering only gradually, lightly curved. Apical part with 29 narrow but strong ribs rather uneven in strength, but all much narrower than the interspaces. As the shell grew, the ribs became relatively broader, so that anteriorly they are about equal in width to the interspaces. An interstital thread tends to appear in the interspaces, especially in the anterior third. Some of the earlier appearing of these became a good deal stronger. Growth lines are strongly marked throughout.

Length, 73 mm.; diameter (posterior), 2.2 mm.; (anterior), 7.5 mm.

Locality: Hampden Beach. (Bortonian.)

This *Dentalium* was collected at Hampden Beach (i.e., Onekakara) almost 100 years ago by Walter Mantell. (1850, *Quart. Journ.*, vol. 6, p. 331, pl. 28, f. 15). Zittell (*Novara Exp., Geol.*, vol. 1, pt. 2, p. 45) identified Hochstetter's Nelson specimens with the Hampden species and gave the name *D. mantelli* without, however, naming a type. Suter (1914, p. 32) accepted this identity, and stated that the type was in the "K.K. Hofmuseum, Vienna." It is not clear whether this was an actual designation of type, or merely a statement based on the idea that Zittel's specimen was automatically the type. In any case, it is best taken as a designation of type. The Hampden shells, however, are easily distinguished by their narrow ribs and wide interspaces, so they deserve specific recognition.

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Preferred Orientation of Olivine Crystals in Peridotites, With Special Reference to New Zealand Examples.

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Introduction.

During the last eight years several papers dealing with preferred orientation of olivine in peridotites, olivine-nodules of basalts, and olivinites of metamorphic origin have appeared (e.g. Andreatta 1934, 1935; Ernst 1935; Phillips 1938). From these it would seem that strong preferred orientation of the component crystals commonly develops during deformation of olivine-rocks, and that in the case of peridotites such deformation may originate during emplacement of a largely crystalline intrusive mass. Certain orientation rules have already been established for olivine in rocks of different origins. But before satisfactory conclusions can be reached as to the mechanism and causes of the orienting processes, or the mode of development and petrofabric significance of such frequently observed phenomena as undulose extinction and lamellar structure in olivine, additional data must be obtained from rocks of widely different age and geographic occurrence. The present paper is a contribution to this end, and includes fabric data for typical New Zealand peridotites and olivine-nodules, with which are compared olivine fabrics of certain well-known European rocks of like composition.

Parting, Translation-lamellae and Undulose Extinction in Olivine.

Olivine has a distinct cleavage parallel to (010) and a less perfect cleavage parallel to (100). In the olivine of peridotites this second plane of mechanical weakness (perpendicular to γ) may be rendered more obvious by the presence of minute rod-like opaque or semi-opaque schiller inclusions which tend to be sharply oriented in (100) of the host crystal (cf. Harker 1919, p. 84). Among the rocks discussed in this paper this feature is particularly well shown in some of the fresh black peridotites of Rum (e.g. 7497*) described by Harker (1908), and a partially serpentinised dunite (5308) from the vicinity of Bluff (Service 1937, p. 212, no. 208). The black peridotite of Abhuinn Fiadh-innis, Rum, has been described by Phillips (1938, p. 134) as showing a remarkable development of lamellae parallel to (100), but in the writer's sections of this rock it is difficult to estimate the relative importance of fine schiller inclusions and of actual planes of parting in determining this sharp,

* Unless otherwise indicated, numbers refer to specimens and sections in the collections of the Geology Department, University of Otago.

finely lamellar appearance, as seen under high-power magnification using a universal stage without the analyser. Iddings (1906, p. 370) mentions inclusions of ilmenite arranged parallel to (100) in the olivine of some basalts, so that in general the presence of schiller inclusions of this type in olivine is not necessarily connected either with plutonic conditions of crystallisation or with deformation.

Certainly of deformational origin, however, are closely-spaced, discontinuous but sharply-defined lamellae parallel to (100) that may be observed in sections of many New Zealand dunites when viewed between crossed nicols. In general appearance these recall the translation-lamellae of deformed quartz figured in a recent paper by H. W. Fairbairn (1941, pl. 2, fig. 1), and are so interpreted by the present writer (cf. Ernst, 1935, p. 153). The olivine lamellae are very closely spaced, usually are restricted to parts of any particular grain, and not infrequently terminate before reaching the grain boundary. In a random section as seen between crossed nicols with an ordinary microscope the lamellae fall into two alternating series with a difference of 5° to 10° in extinction position, thus simulating polysynthetic twinning (cf. Harker, 1919, p. 84). Careful measurements on a universal stage show, however, that the crystallographic orientations of adjacent lamellae are always only slightly different; indeed, the lamellar structure often disappears when the plane of the lamellae is brought parallel to the axis of the microscope-tube. Even where the difference in optic orientation is a maximum, stereographic plotting of α β and γ for each set of lamellae shows that the only twin relationships that could be responsible for the observed phenomena would be irrational types, viz. either (a) normal twinning with the twin axis inclined at about 5° to γ (= crystallographic *a*), or (b) parallel twinning with the twin plane inclined at 85° to γ and the twin axis at 3° to 5° to α or β. Twinning must therefore be eliminated as a possible explanation, and translation-gliding remains the most likely mode of origin for lamellar structure subparallel to (100) in olivine. Buerger (1930, p. 13) has noted that in general translation-gliding is commonly accompanied by slight changes in optic orientation along the translation planes.*

Undulose extinction, so commonly observed in the olivine of peridotites in general, is particularly prominent in the dunites and other peridotites of the western portion of the South Island of New Zealand. Within any large undulose superindividual, the boundaries of the subindividuals or extinction-bands are invariably subparallel to (100) and not infrequently take the form of sharply defined surfaces of rupture. If the lamellar structure referred to in the preceding paragraph is also present, it maintains constant orientation within any one subindividual, but there may be slight differences of orientation between lamellae of adjacent subindividuals.

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* Similar sharply defined lamellae parallel to (100) are developed in crystals of enstatite associated with lamellar olivine in South Island peridotites. Though this is highly suggestive of origin by translation-gliding in such cases (cf. N. F. M. Henry, *Min. Mag.*, vol. xxvi, pp. 179–189, 1942), universal application of this explanation to cover all cases of lamellar hypersthenes in norites, dolerites, etc., is in the writer's opinion still unwarranted.

Considerable attention has recently been given to the phenomenon of undulose extinction, especially as it occurs in deformed grains of quartz (e.g. Sander 1930, pp. 173–180; Knopf 1938, pp. 170, 171; Hietanen 1938, pp. 33–35; Fairbairn 1941, pp. 1273–1276). It is generally agreed that the undulatory bands result from a permanent distortion of the space-lattice, which not infrequently leads at last to rupture and slight translation parallel to the boundary surfaces of the subindividuals. According to Hietanen (*loc. cit.*) the primary mechanism by which undulose extinction develops in bands parallel to the vertical axis in quartz is translation and flexure on the basal plane; Fairbairn on the other hand favours a hypothesis of translation governed by an invariable glide line (the edge $m:r$) and variable irrational glide-planes inclined at low angles to the basal plane. In both cases the causal translation movement is pictured as operating on planes perpendicular to the trend of the undulose bands.

If a like mechanism is assumed for the origin of undulose extinction in olivine, certain conditions follow immediately with regard to the relative parts played by glide-directions and glide-planes in the deformation. The possibility of deformation governed by a definite glide-plane without any predominating glide-direction must be discarded for olivine. For in such a case the boundaries between the extinction bands of any crystal could be parallel to *any* plane perpendicular to the glide-plane; actually they are restricted to a single crystallographic plane, (100). All that is necessary to produce the effects observed in olivine is the presence of a controlling invariable glide-direction parallel to γ (*a* crystal axis); translation could occur on any plane containing γ, i.e. on any plane in the zone [100], or it could be restricted to an invariable plane in that zone. It is interesting to note at this point that in olivine the direction of maximum atomic density, and hence the most likely potential glide-direction, is the *a* crystal axis (cf. Bragg 1937, p. 147); furthermore on the similar grounds the most likely glide-plane is (010).

The crystallographic planes and directions of structural weakness with which petrofabric data should be compared are as follows:—

(010); $\perp\alpha$; most distinct cleavage; on theoretical grounds the most probable glide-plane.

(100); $\perp\gamma$; indistinct cleavage; most pronounced plane of schillerization and accompanying parting; plane of microscopically observable translation-lamellae, and undulose banding.

[100]; $=\gamma$; on theoretical grounds the most likely glide-direction; glide-direction assumed for development of undulose extinction by flexure-gliding in a plane or planes perpendicular to the resultant banding.

[001]; $=\beta$; on theoretical grounds a probable glide-direction.

Banding and Fissility in Peridotites.

Parallel banding, usually interpreted as a primary flow structure, is well known in peridotites. In many New Zealand dunites thin, discontinuous black bands rich in chromite, usually only a few

millimetres thick, alternate with wider green olivine-rich bands poor in chromite. Flow banding is also well exhibited in the Tertiary peridotites of Rum and Skye as described by Harker (1904, 1908). This includes both small-scale alternation of layers respectively rich and poor in a spinellid mineral (e.g. Harker, 1904, pp. 71, 72), and banding of a much more striking nature, clearly conspicuous in the field, such as that resulting from variation in the feldspar content of interlaminated sheets of peridotite and allivalite on the island of Rum (Harker, 1904, pp. 75, 76, pl. ii; 1908, pp. 72–74). Harker's interpretation of all these parallel structures as the result of magmatic flow is supported by marked dimensional parallelism of the undeformed plagioclase tables in many of the allivalites and troctolites, and by the definite tendency for elongated olivines to show dimensional parallelism in Hebridean peridotites investigated by Phillips (1938, p. 131).

There are strong objections to any hypothesis of origin of banded structures in the unserpentinised dunites of New Zealand and the Hebridean province, other than that of laminar flow in a partially, perhaps almost completely crystallised magma. Laminated structure very commonly develops in crystalline schists by metamorphic differentiation through the medium of aqueous pore-solutions, but an analagous mechanism could hardly be responsible for the structure of dunites in which hydrous minerals such as serpentines, chlorites, talc, etc., are completely lacking. The same objection, together with the absence of recognisable replacement textures weighs against the possibility of late magmatic introduction of chromite in the present case, though this mode of origin is probable for some chromite-rich rocks associated with New Zealand peridotites, and has also been suggested for particular instances of partially serpentinised banded chromite-dunites in other parts of the world (e.g., Rynearson and Smith, 1941) Cataclastic origin may also be ruled out, for many of the rocks concerned show no other certain evidence of deformation than a slightly undulose condition observable in some olivine grains, while the chromite or picotite of the dark layers typically is in sharp undeformed octahedral crystsals. A totally different type of banding not infrequently noted in basic plutonic rocks is that shown by norites and gabbros of the Bushveld and Stillwater type (e.g., Hess 1938). The controlling magmatic process, rhythmic gravitational settling of heavier and lighter crystals in a liquid subject to periodic slight turbulence (Hess 1938, p. 266), cannot, however, be applied to banded dunites that have been emplaced in the form of vertical or steeply dipping sills as in the case of the great peridotite masses of the South Island of New Zealand.

While accepting the hypothesis of flow-banding, the writer would draw attention to certain petrographic details of a picotite-dunite (7496) from South of Alt a'Chaoich, Skye (Harker 1904, pp. 71, 72, Fig. 13), that make it difficult to picture the exact sequence of events during crystallisation and flow of the magma in question. The light coloured bands consist of olivine, with accessory scattered grains of poorly translucent chromite, while the dark layers are made up of idiomorphic grains of a distinctly more translucent picotite wholly

enwrapped by highly allotriomorphic interstitial basic plagioclase ($An_{76}\pm_8$) a mineral which is completely lacking in adjacent olivine-rich bands. These two assemblages of minerals can hardly be products of simultaneous crystallisation from the same magma.

Less conspicuous than flow banding, but nevertheless of fairly general occurrence in peridotites, is a slight fissility two types of which are to be distinguished:—

(a) In dunite-mylonites, such as the rock from Milford Sound described in a later section, the fissility is a schistosity of cataclastic origin resulting from dimensional parallelism of elongated fragments of ruptured olivine grains.

(b) More general in its occurrence is fissility governed by dimensional parallelism of elongated grains that do not appear to be of cataclastic origin. Such a fissility could be the result of flow in a partially crystalline mass, especially if the rock tends to split parallel to the trend of flow banding, as appears to be the case with Hebridean peridotites and allivalites. However, there are other possible modes of origin that might at least play an auxiliary role—namely, deformation of grains by flattening (as in the flattened quartz grains of many granite gneisses), or on the other hand elongation of grains during crystallisation, along surfaces of maximum ease of growth such as might be provided by flow surfaces in the later stages of consolidation (growth orientation controlled by Wegsamkeit). Fabric analysis should yield some information as to which of these orienting process is responsible for fissility in any given case of a fissile peridotite.

Olivine Fabrics in Peridotites and Related Rocks.

(a) *Previously Recorded Fabric Data for Olivine.* Space-lattice orientation of olivine crystals with (010) parallel to the schistosity (i.e. α perpendicular to the schistosity) was first recorded by Andreatta (1934, 1935) for olivine-rocks believed to be of metamorphic origin.* The same orientation rule was confirmed by Ernst (1935) for Norwegian olivine-schists. From the even spread of the β and γ directions within the schistosity-plane Ernst (*op. cit.*, p. 149) concluded that in olivine crystals (010) is a glide-plane but that there is no glide-line within this plane. The same writer established the existence of identical fabrics in olivine-nodules enclosed within basaltic rocks from various German localities, and cited this fact as evidence supporting the view that such nodules are not products of magmatic segregation but represent fragments of older olivine-rocks that have been caught up in the basaltic magma prior to eruption. The frequent development of translation-lamellae in the olivine of such nodules was also cited by Ernst (*op. cit.*, p. 153) as evidence of deformation dating from some period before immersion in the basaltic magma. Measurement of grain-size in sections cut perpendicular to the fabric plane in which (010) of the olivine tends to lie, shows that the olivine-nodules described by Ernst have a slight but distinct schistosity determined by dimensional orientation of somewhat lensoid grains.

* In Andreatta's diagrams there is also a much less pronounced tendency for γ to lie perpendicular to the shear-planes.

The Hebridean peridotites and allivalites described by Phillips (1938), though apparently unaffected by any deformation subsequent to intrusion, are slightly fissile rocks with distinct dimensional orientation of the component grains. There is usually strong preferred lattice-orientation, with (010) parallel to the plane of fissility just as in the rocks described by Ernst; γ is said to be evenly distributed within the plane of fissility, though one diagram (Phillips, *op. cit.*, Fig. 2) shows a pronounced maximum within the γ-girdle. In the Hebridean peridotites, as in the case of Ernst's olivine-nodules, strong development of translation-lamellae parallel to (100) is said to be accompanied by weakening of the α-maximum and development of an α-girdle (Phillips, *op. cit.*, p. 134). Phillips concludes that the "stresses acting during the emplacement of an olivine-rich intrusive already largely crystalline" can develop an olivine fabric identical with that previously considered diagnostic of olivine-schists of metamorphic origin; furthermore, the presence in basalts of olivine-nodules with such a fabric could be explained by assuming derivation from peridotite intrusions belonging to an earlier phase of the same igneous cycle.

It may be mentioned here that some confusion has arisen from Fairbairn's (1937, p. 36) misquotation of Andreatta as finding (001) parallel to the shear-surfaces, and from a statement by Eskola (1939, p. 307) that Phillips has recorded orientation of olivine grains with (100) in the shear-planes (doubtless referring to Phillips's description of translation-lamellae parallel to that plane).

(b) *Fabrics Resulting from Movement of Olivine Crystals Immersed in a Liquid Medium.* To determine to what extent a space-lattice orientation controlled by a primary dimensional orientation might develop by movement of olivine crystals surrounded by a liquid medium, fabric diagrams were prepared for the olivine of two basaltic rocks showing pronounced flow structure, and for a specimen of peridotite from the gravitationally differentiated sill of Lugar in Ayrshire.

In these, as in most of the other fabric diagrams in this paper, the α, β and γ directions of 50 olivine grains measured in several traverses of each thin section have been plotted separately. This number is usually sufficient to demonstrate the essential features of preferred orientation in that it allows clear recognition of maxima and girdles in the diagram. Individual submaxima are probably of no significance, however, and it must be remembered that maxima which actually appear as groups of submaxima would be more completely filled in if one or two hundred grains were measured. Where, as with oriented olivine fabrics, the degree of preferred orientation is high and the pattern is simple, it is more profitable to measure in as many rocks as possible the minimum number of grains necessary to bring out the pattern of the fabric, than to investigate a few specimens in greater detail.

In Figs. 1–3 the orientation of olivine in a Tertiary mugearite (P.5561†) from Jeffrey's Hill, Dunedin district, is recorded. The

† The two rocks P.5561 and P.5564 are from the collections of the N.Z. Geological Survey.

rock was selected as being likely to show the maximum effects of flow on orientation of olivine, since the slender laths of andesine present have a pronounced fluxional arrangement, and the olivine crystals have a simple uniformly developed prismatic habit with obvious elongation parallel to the *a* crystal axis (γ). The only prominent faces are those of the brachydome (021); sections parallel to *a* therefore have elongated rectangular outlines (0.4 mm. x 0.2 mm.) while those perpendicular to *a* are simple rhombs with interfacial angles of 81° and 99°. Figs. 1–3 nevertheless fail to reveal any significant space-lattice orientation of the olivine crystals, while the same holds true for diagrams prepared for a coarser mugearite (P.5564) from the nearby locality of Scroggs Hill. Separate plotting of the axes of coarser grains (0.5 mm. to 1 mm.) and those of the smaller granules (0.1 mm. to 0.3 mm.) in P.5564 also failed to bring out any trace of preferred orientation of space-lattice in either type of olivine crystal. A specimen from the hornblende-peridotite layer of the differentiated teschenite sill of Lugar, Ayrshire, was selected for fabric measurement as an example of an aggregate of olivine crystals, the fabric of which has been determined by gravitational settling and has not been affected by subsequent deformation (Tyrrell 1917, pp. 112, 125–127). The resulting diagrams, Figs. 4–6, show no indications of preferred orientation of the olivine, which makes up about 60% of the thin section and takes the form of rounded equant grains averaging 0.2 mm. in diameter.

(c) *Fabrics of Banded Dunites.* Chromite-orpicotite-dunites with marked parallel flow banding are represented by 7494, 7495 (both from Dun Mt., Nelson), and 7496 (glen south of Alt a'Chaoich, Skye). In all three specimens black layers a few millimetres in thickness, consisting mainly of chromite or of picotite, alternate with wider olivine-rich bands in which chromite is but a sparsely distributed accessory. The Nelson dunites consist of olivine, chromite, and minor enstatite; in the rock from Skye, on the other hand, the associations olivine-chromite and picotite-plagioclase are alternately developed in adjoining bands. The grains of olivine are rounded, and for the most part slightly undulose, but the sharp lamellar structure associated with a strongly undulose condition in other peridotites here described is altogether lacking, as also is schiller structure parallel to (100). As seen in sections cut at right angles to the banding, many of the grains of olivine in 7494 and 7496 are slightly but distinctly elongated in the plane of banding of the rock, but in 7495 the grains are more nearly equant and dimensional parallelism is lacking.

The fabric of the typical banded dunite of Nelson (7495) is illustrated in Figs. 7–9 based on 50 sets of measurements. The α-diagram shows a strong maximum approximately at right angles to the plane of banding (s). As is commonly the case with peripheral maxima in general, elongation of the maximum along the circumference of the projection is in the main apparent and due to elliptical distortion of small circles of the sphere as projected upon an equal-area projection. The diameters of the sectors enclosed by the 8% and 4% contours in Fig. 7 correspond respectively to angular distances of 22° and 45° measured radially, as compared with 30° and

60° measured along the circumference of the diagram. The actual tendency for the maximum of Fig. 7 to spread in an incipient girdle is therefore slight.

In Fig. 9, on the other hand, there is a distinct though incomplete girdle of γ-axes, indicating a strong tendency for γ to lie within or close to s and to be concentrated especially within a limited sector in this plane. In Fig. 8 β approximates much less closely to the plane of banding than does γ in Fig. 9, and tends to fall within a poorly defined maximum corresponding to the break in the γ-girdle. From this lack of correspondence in the distribution of β and γ it would appear that orientation of the olivine crystals is governed by some more complex rule than the simple tendency for α to lie perpendicular to s that is indicated by Fig. 7. This conclusion also emphasises the advisability of recording orientation diagrams for all three indicatrix axes rather than that for α alone.

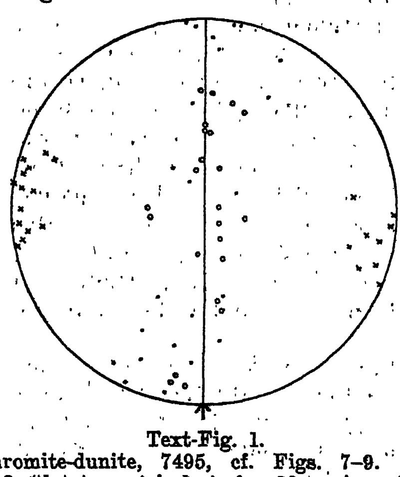
Replotting of α, β and γ for selected grains whose orientation appears definitely related to s in section 7495, brings out the following facts:—

(1) The area of maximum concentration in Fig. 7 contains the poles of 23 α-axes out of a total of 50 measured.

(2) Out of 50 measured grains 20 have β inclined to s at angles of 20° or less; for 19 of these α falls within the maximum of Fig. 7.

(3) A total of 41 grains have γ inclined to s at angles of 20° or less; for 21 of these α falls within the maximum of Fig. 7.

(4) In Text-fig. 1, α, β and γ for the 23 grains having α within the maximum of Fig. 7 are plotted separately. For these grains β and γ are distributed just as within the girdles of Figs. 8 and 9. Thus the area of concentration of γ in Fig. 9 is shown to be an imperfectly filled elongated maximum, all parts of which bear the same relation to the simple maximum of the α-diagram.



Text-Fig. 1.

Banded chromite-dunite, 7495, cf. Figs. 7–9. Plot of α (crosses); β (dots), γ (circles) for 23 grains of olivine for which α falls within the maximum of Fig. 7. The vertical line is the projection of the plane of banding.

Taking these additional data into consideration, it is possible to state the orientation rules for olivine in the dunite 7495 as follows:—

(1) α tends to lie perpendicular to the plane of banding, s.

(2) γ tends to lie sub-parallel to s regardless of whether α conforms to rule (1) or not.

(3) γ (and therefore β) tends to be concentrated over a limited range of direction in s.

The orientation of olivine in the second banded chromite-dunite from Nelson (7494) is recorded in Figs. 10–12, which show distinct maxima for α, β and γ in mutually perpendicular directions; of these the α concentration is most clearly defined and is normal to the plane of banding.

A somewhat different condition is illustrated in Figs. 13–15 which represent the orientation of 50 grains of olivine in a banded picotite-dunite from Alt a'Chaoich, Skye. In the α-diagram there is the usual maximum at 90° to s, with a tendency to elongate into an incomplete girdle; but in contrast with the two cases described above, the β-girdle parallel to s is more strongly developed than that for the γ-axes.

(d) *Fabrics of Fissile Non-banded Dunites.*

Most typical New Zealand dunites, as exemplified by specimens from the type area of Dun Mt., Nelson and the Olivine Range of South Westland are non-banded rocks in which chromite (or picotite) is of only accessory rank. The majority of the specimens seen by the writer are non-fissile rocks that break irregularly beneath the hammer, but in a few instances a slight fissility is apparent. The fabric of one of these slightly fissile dunites from Dun Mt. (7493) has been investigated and compared with those of a slightly feldspathic fissile dunite from Alt a'Chaoich, Skye (7498) and a foliated black peridotite from Rum (7497).

In the rock from Skye grains of olivine showing faintly undulose extinction but no trace of lamellar structure are locally enwrapped by small, highly allotriomorphic crystals of basic plagioclase that make up less than 1% of the total composition. The fabric (Figs. 16–18) differs but little from that of the banded picotite-dunite (Figs. 13–15) from the same locality. The α-maximum perpendicular to the plane of fissility (s) is somewhat stronger in Fig. 16 than that of Fig. 13, and both β and γ tend to be distributed evenly in equally well defined girdles parallel to s. The maxima in these β- and γ-girdles are fortuitous, for they do not correspond in partial diagrams each prepared from 25 sets of measurements. It is probable, though not necessarily the case, that banding and fissility in the dunites of Alt a'Chaoich are similar in origin and tectonic significance.

In the fissile dunite from Dun Mt. (7493) the grains universally show very marked undulose extinction which in many instances has developed to the stage when the extinction bands of a super-individual are separated by sharply defined fractures (approximately perpendicular to γ). Translation-lamellae perpendicular to γ are commonly observable between crossed nicols. Both these phenomena

are more pronounced than in any other rock described in this paper. The orientation of α, β and γ for fifty distinct grains of olivine is depicted in Figs. 19–21; where, as frequently is the case, the positions of the indicatrix axes vary considerably within a superindividual, the mean position of the axis in question has been plotted as a single point on the projection. The most clearly defined feature of the olivine fabric is a sharp girdle of γ-axes in a plane inclined at a low angle to the plane of fissility (since the latter is hard to locate precisely in a hand-specimen, it is possible that the γ-girdle actually coincides with the plane of fissility). In Fig. 20 there is a very strong β-maximum perpendicular to the plane of the γ-girdle, and for the corresponding crystals α falls within the girdle of γ-axes (e.g., points adjacent to Y in Fig. 19). For other crystals, however, α is inclined to the plane of the γ-girdle at angles 60°–70° (X in Fig. 19) while β approaches to within 20° or 30° of this plane (e.g., points near X, Fig. 20).

Orientation of olivine in 7493 is therefore governed by at least two principles:

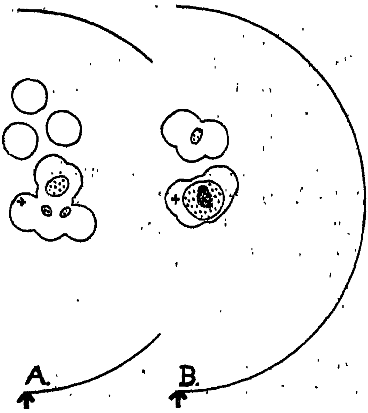
(1) β lies normal to *s*, where *s* is a plane slightly inclined to or possibly coincident with the megascopic plane of fissility. About half the grains measured approximate to this orientation.

(2) γ lies approximately parallel to *s*. This rule affects all crystals, whether β is normal to *s* or not.

To illustrate the relationship of undulose extinction in superindividuals to the fabric of the rock as a whole, the measured range of α, β and γ in the component parts of sixteen strongly undulose superindividuals in shown separately in Figs. 22–24. (The mean position of α, β and γ for each of these has already been included in the projections from which Figs. 19–21 were constructed). The strongest divergence within a superindividual is almost invariably shown by γ and the other indicatrix axis (sometimes α, sometimes β) that falls close to the γ-girdle. Furthermore, these axes tend to diverge subparallel to the girdle, so that lines joining the poles of a given axis (e.g., γ) in a superindividual trend subparallel to the projection of the γ-girdle. On the other hand, there is no observable regularity in the direction of divergence of that axis (α or β) which is steeply inclined to the γ-girdle (e.g., 2, 3, 7, 8 in Fig. 22; grains 4, 5, 6, 16 in Fig. 23). The maximum observed divergence was 30° for γ in grains 6 and 13; corresponding divergences of α and β respectively were 22° and 15° in the one case, 2° and 24° in the other (all values are regarded as correct only to $\pm$ 3°).

From comparison of Figs. 19–21 with Figs. 22–24 it would appear that no profound change in fabric can be attributed solely to grain deformation that has been sufficient to cause the very marked undulose extinction recorded for olivine in this rock. The γ-girdle of Fig. 21, and its imperfect equivalent in Fig. 19, have not been strongly affected, though the attenuated maxima within the girdle of Fig. 21 may well have been weakened (or accentuated) during this phase of deformation. The extent to which the maximum of Fig. 20 may have been weakened (or emphasised) during development of undulose extinction is illustrated in Text-fig. 2. For each of the nine undulose

grains of Fig. 23 (1, 4, 5, 6, 10, 11, 14, 15, 16), that approximate to the rule $\beta \perp s$, two extreme positions of β have been selected and re-plotted so as to give respectively the greatest (A) and the least (B) possible scattering of points on the projection.



Text-Fig. 2.

Dunite, 7493, cf. Figs. 20, 23. Plot of 9 β-axes (grains 1, 4, 5, 6; 10, 11, 14, 15, 16) from the maximum of Fig. 23. Positions of β within each undulose crystal have been selected so as to give greatest (A) and least (B) possible scattering of points. Contours 5, 3, 1 points per 1% area of projection.

The third example of a fissile peridotite is the "black olivine-rock" (7497) from south of Abhuinn Fiadh-innis, Rum, described by Harker (1908) and subjected to fabric analysis by Phillips (1938, p. 134 and Text-fig. 6). The writer's specimen is only poorly fissile and has a distinct lineation, the direction of which varies slightly within the plane of fissility. It consists of faintly undulose grains in which schiller structure and sharply defined parting parallel to (100) are very well shown, but which show no trace of the translation-lamellae that are so conspicious between crossed nicols in many New Zealand dunites. The grains vary in size, but have no dimensional orientation in relation to the plane of fissility. The fabric diagrams (Figs. 25–28) show a more definite preferred orientation of the space-lattice than that recorded by Phillips, though less clearly defined than, and of a different type from, that so far encountered in other Hebridean peridotites. The α-diagram (Fig. 25) shows an incomplete girdle about a point (approximating to the pole of the megascopic lineation) lying in the plane of fissility (s), and a minimum perpendicular to s; positions of the maxima within the girdle vary in partial diagrams. In Fig. 26 β tends to approach a point in s that coincides with the centre of the α-girdle. On the other hand γ (Fig. 27) appears to lack regular preferred orientation. The writer finds it difficult to reconcile this last feature with the conclusion of Phillips (*op. cit.*, p. 134) that the peculiarities of fabric in this rock are related to the unusually perfect development of parting normal to γ, except in so far as the well developed schiller structure and poorly oriented fabric might both be connected with absence of stress after intrusion.

(e) *Fabrics of Peridotites Lacking Both Banding and Fissility.* Specimen 1380 (Turner 1933, p. 258) is typical of the fresh non-fissile non-banded harzburgites of South Westland. Olivine makes up more than 80% of the total composition. The grains range from 0.5 mm. to 2 mm. in diameter, and commonly show distinct undulose extinction accompanied by translation lamellae-parallel to (100) when observed between crossed nicols. No preferred dimensional orientation of grains could be detected.

In spite of the absence of megascopically observable parallel fabric, the orientation of the space-lattice is strongly marked and conforms to a simple pattern (Figs. 28–30). A single strong maximum in the α-diagram tends to elongate along an arc the centre of curvature of which is the γ-maximum of Fig. 30. In the plane perpendicular to the concentration of α-axes, β and γ are restricted to clearly defined sectors (Figs. 29 and 30). As with similar fabrics recorded for banded dunites, the maximum for γ is more sharply defined than that for β, and the tendency for γ to lie in the plane perpendicular to the α-maximum is more marked than is the case with β (cf. with Figs. 7–9). Measurement of the range of α, β and γ in each of three large, strongly undulose crystals gave 20°–25° as the maximum divergence of any indicatrix axis; no regularity in direction of divergence was noted.

A representative of the Nelson dunites lacking banding and fissility is 7505, which is composed of fresh equant grains 0.1 mm. to 0.5 mm. in diameter with strongly developed undulose extinction and translation-lamellae normal to γ. The section is traversed by many cracks of highly variable orientation, but there is one set of curving subparallel cracks that are particularly prominent, continuous and constant in trend, and apparently independent alike of the orientation of the crystals through which they pass and of the presence of undulose extinction or translation-lamellae in these. The space-lattice orientation of the olivine crystals is illustrated in Figs. 31–33. This is the only instance, among the rocks investigated by the writer, of a fabric in which the α-axes fall in a sharply defined nearly complete girdle. There is clearly a tendency for β (Fig. 32) to occupy the same girdle, though the orientation is less sharp than in the case of the α-girdle. In Fig. 33 γ is strongly concentrated in a single maximum perpendicular to the girdle of α and β. In the absence of macroscopically visible *s*-surfaces the fabric might represent a single set of s-surfaces to which γ is normal, or a B-tectonite fabric with γ parallel to the B-axis. The presence of abundant subparallel cracks inclined at high angles to γ strengthens the latter alternative, if it is assumed that the cracks in question are approximately parallel to the *ac* fabric plane, the commonest orientation for tension-fractures in B-tectonites.

The third example of a peridotite without megascopically visible *s*-surfaces is a dunite (5308) from the vicinity of Bluff, previously described by H. Service (1937, pp. 207, 212, no. 208). The rock occurs as a small mass, possibly a late dyke, associated with the well-known norites that occur extensively in this region. The thin section consists of equant grains of olivine 1 mm. to 5 mm. in diameter usually showing pronounced schiller structure parallel to

(100). In contrast with the West Coast dunites the Bluff rock appears not to have been affected by stress since consolidation, for not only is there no trace of undulose extinction in the olivines, but the serpentine partially replacing the olivine grains is chrysotile with mesh-structure instead of the antigorite almost universally present in serpentinised peridotites from the West Coast. The fabric (Figs. 34–36) is poorly defined and somewhat resembles that of the black peridotite from Rum illustrated in Figs. 25–27. In the α-diagram is a vaguely defined maximum (present in each of two partial diagrams which are combined into Fig. 34), while β clearly tends to lie in a girdle perpendicular to the α-maximum. On the other hand there is no preferred orientation of γ (Fig. 36).

(f) *Fabric of Cataclastic Dunite.* The peridotites described by Marshall (1905) from Anita Bay, Milford Sound, include a steeply dipping sill of dunite interbedded with amphibolites of high metaphoric grade. The dunite (7491) shows no trace of serpentinisation, but has evidently undergone extreme cataclasis, which has reduced the grain-size to between 0.03 mm. and 0.05 mm. and imparted a distinct fissility to the hand specimen. Sections cut perpendicularly to the plane of fissility (s) show that this structure is determined partly by dimensional parallelism of the larger elongated granules and partly by a tendency for subparallel streaks of coarser and finer material to alternate. There is also a tendency for scattered granules of chromite to lie in discontinuous strings parallel to s. The individual grains of olivine in the writer's sections are free from schiller structure, translation-lamellae and undulose extinction, nor is there any tendency for grouping of grains into superindividuals. In sections of the same rock described by Marshall (*op. cit.*) undulose extinction and granulation are recorded in residual larger grains enclosed in the fine-grained matrix.

The fabric of 7491 is illustrated in Figs. 37–39, based on measurements of 50 grains in several widely separated traverses across a single thin section. Complete lack of orientation of the space-lattice is attributed to the destructive process of cataclastic as opposed to plastic deformation of other rocks.

(g) *Fabrics of Olivine-nodules Associated with Basaltic Rocks.* Three New Zealand specimens of olivine-nodules from widely separted localities and different geological environments have been selected for fabric analysis, and the results have been compared with data obtained from a nodule (7499) from Prussia.

The first example (7503) is typical of the numerous small nodules (3 cm. in diameter) that are scattered among the basaltic lapilli of a Pleistocene tuff-cone, Onepoto, Shoal Bay, near Auckland city. In comparison with associated nodules, 7503 is a somewhat fine-grained rock (0.5 mm. to 1 mm.) with no trace of dimensional orientation of the constituent grains of olivine. Many crystals show well defined undulose extinction, with sharp ruptural boundaries between adjacent sectors of any individual, but translation-lamellae were not observed. A little enstatite ($2V = 80°$; sign $+$) and nearly opaque chromite are also present. The fabric diagrams (Figs. 40–42) show pronounced preferred orientation of a somewhat unusual type in

that the only orientation rule is for the α-axes to fall into a well defined girdle indicated by the broken line in Fig. 40. The β- and γ-diagrams show poorly developed submaxima which appear to have no significance. The slight concentrations of β and of γ in the vicinity of the normal (X) to the α-girdle are no greater than can be accounted for by the fact that X is a possible position for any direction in the $\beta\gamma$ plane of all crystals for which α lies in the girdle of Fig. 40.

The second investigated specimen (5100; Figs. 43–45) is a large nodule (10 cm. in diameter) from the Pliocene basalt of Kokonga, in the outer portion of the East Otago petrographic province. Nodules are rare in the basalts of this region. The rock has the composition of olivine-rich lherzolite containing some enstatite, diopsidic augite and picotite in addition to the major constituent. The grain-size varies from 0.5 mm. to 3 mm., and there is no obvious preferred dimensional orientation of grains. Translation-lamellae were not observed, but undulose extinction is conspicuous in many of the larger crystals of olivine. At first glance it would appear that the grains plotted in Figs. 43–45 lack any significant preferred orientation; and this conclusion is strongly borne out by applying the statistical test described by H. Winchell (1937, pp. 21-27), for the distribution of points in any one diagram agrees almost exactly with a theoretical random distribution.‡ Nevertheless it will be noted that the three poorly defined maxima marked X in Figs. 43–45 represent three mutually perpendicular directions in the fabric, and it is a simple

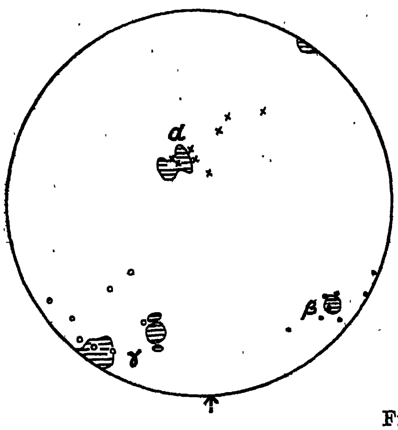
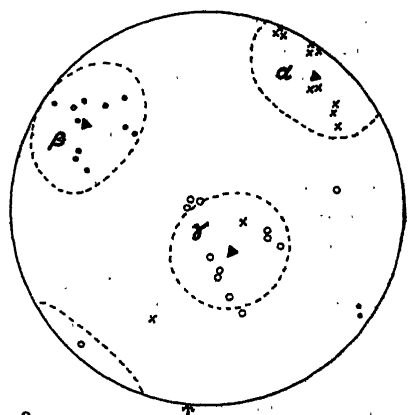


Fig. 3.



Text-Fig. 3.—Olivine-nodule, 5100, cf. Figs. 43–45. Plot of α (crosses), β (full circles), and γ (open circles) for eight grains having β close to the maximum X of Fig. 44. Shaded areas show the positions of maximum X for α, β and γ respectively.

Fig. 4.

Text-Fig. 4.—Olivine-nodule, 6655, cf. Figs. 46–48. Plot of α (crosses), β (full circles) and γ (open circles) for 13 grains having β close to maximum X of Fig. 47. Solid triangles indicate points marked X on Figs. 46–48; broken lines show small circles 25° from X.

‡ A circular net divided into 148 equal squares was superposed upon the "scatter diagram" of axial points. In the case of the β diagram (Fig. 44) the number of squares containing 0, 1, 2 and 3 points respectively was found to be 106, 39, 4 and 1. Corresponding figures for a random distribution are 106, 36, 5, 0. The calculated probability index, P, = 0.45.

matter to test whether or not this is fortuitous, by re-plotting the three axes α, β and γ for each of the crystals (eight in all) in which β lies close to X in Fig. 44 (Text.fig. 3). For each of these crystals it is found that both α and γ closely approach maximum X in their respective diagrams, and a slight but nevertheless significant preferred orientation involving 16 per cent. of the measured grains is in this way established. On the other hand, when α, β and γ are re-plotted for an additional 13 grains, having γ close to X in Fig. 45, the corresponding α and β directions are well scattered within the girdle perpendicular to the γ-maximum, and approach maximum X (though not closely) in three cases only.

The third case is that of a typical large nodule (6655) from the Oligocene marine breccia of Kakanui, North-East Otago. The breccia is of pyroclastic origin and consists of fragments of tachylite and basalt with which are associated plentiful coarse crystals of brown hornblende and large nodules of peridotitic composition, and a variety of rocks consisting of such minerals as garnet, hornblende, augite, biotite, etc. (Thomson 1907). Biotite-schists and other metamorphic rocks are also represented in the breccia.

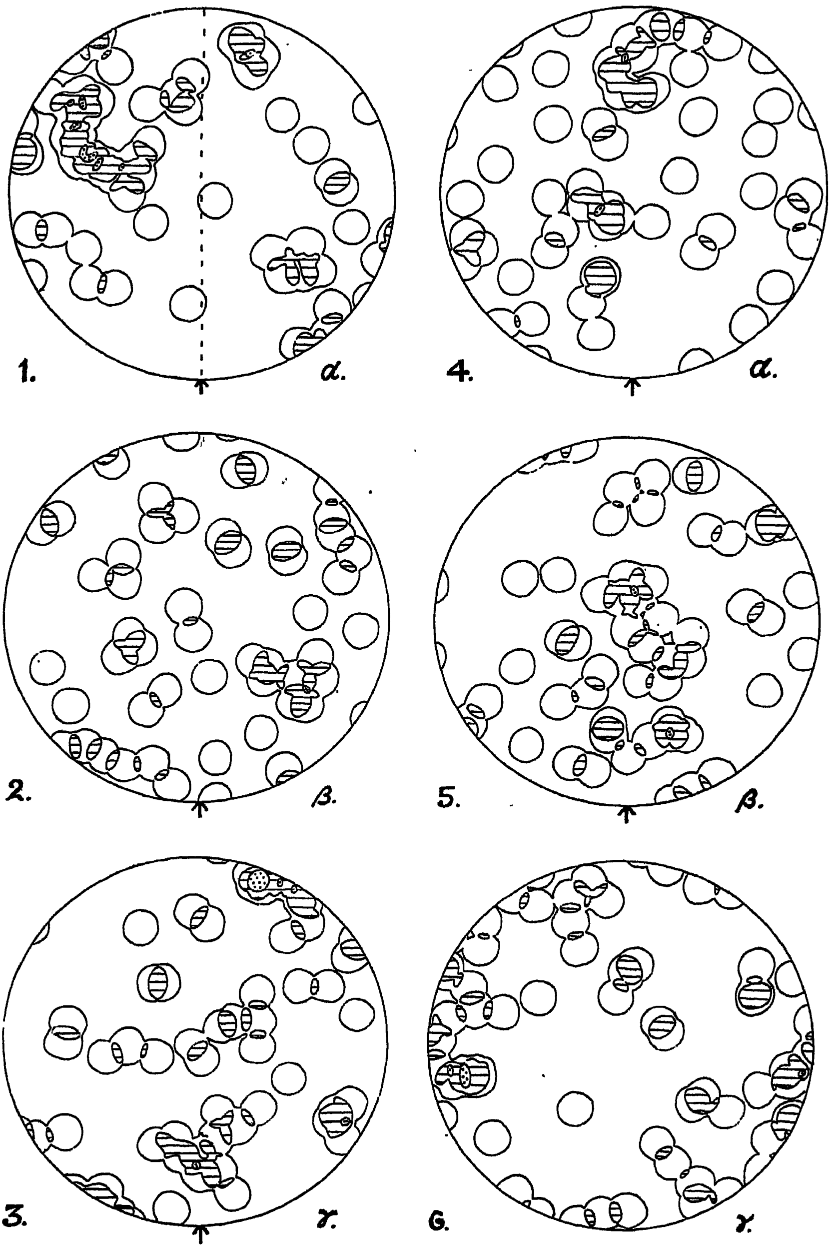
The nodule 6655 is a lherzolite containing abundant picotite, and petrographically resembles the rock from Kokonga just described, except that the grain is rather coarser in 6655. Undulose extinction is conspicuous and translation-lamellae quite lacking in the grains of olivine. The orientation of all available grains (35 in number) is shown in Figs. 46–48, each of which has a rather vaguely defined concentration of axes round a single point X. By re-plotting α, β and γ for 13 crystals whose β axes approach parallelism with X (Text-fig. 4), it is found that for 11 of these grains α and γ lie not far distant from maxima X of Figs. 46 and 48 respectively. It is therefore concluded that the grains of olivine tend to some extent to develop a preferred orientation in which α, β and γ all occupy constant positions in the rock fabric.

The fabric of the olivine nodule (7499) enclosed in basalt from Prussia is not figured here since it conforms to the descriptions given by Ernst (*op cit.*). There is a strong concentration of α-axes (maximum = 18% per 1% area, in 50 measured grains) with a β-γ-girdle perpendicular to this. It should be noted, however, that within this there are definite mutually perpendicular maxima (10%–12%) for β and γ respectively.

Conclusions.

The conclusions put forward below are based on the petrofabric studies embodied in this paper, taking into account also the findings of the previous authors cited. Further work of the same nature will be necessary to verify the extent to which they may be applied, or have to be modified, in interpreting olivine fabrics in general.

(1) Flow in basic lavas containing suspended prismatic olivine crystals fails to produce preferred space-lattice orientation of olivine (Figs. 1–3) even though it may have given rise to pronounced fluxional arrangement of the accompanying laths of feldspar. This raises the possibility that dimensional parallelism of the feldspars in volcanic rocks may be governed by growth of crystals in the surfaces of flow of the viscous magma according to Sander's principle

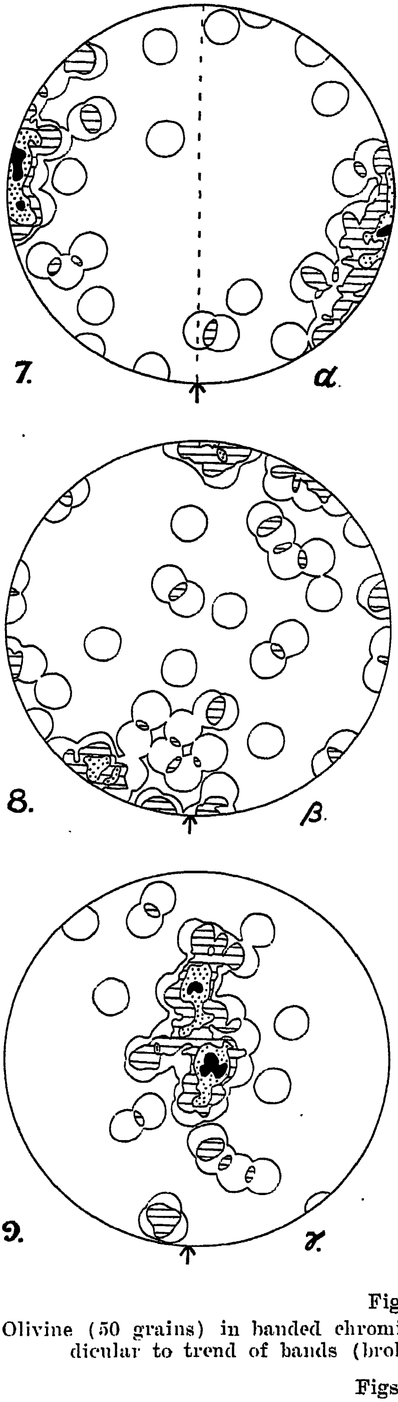


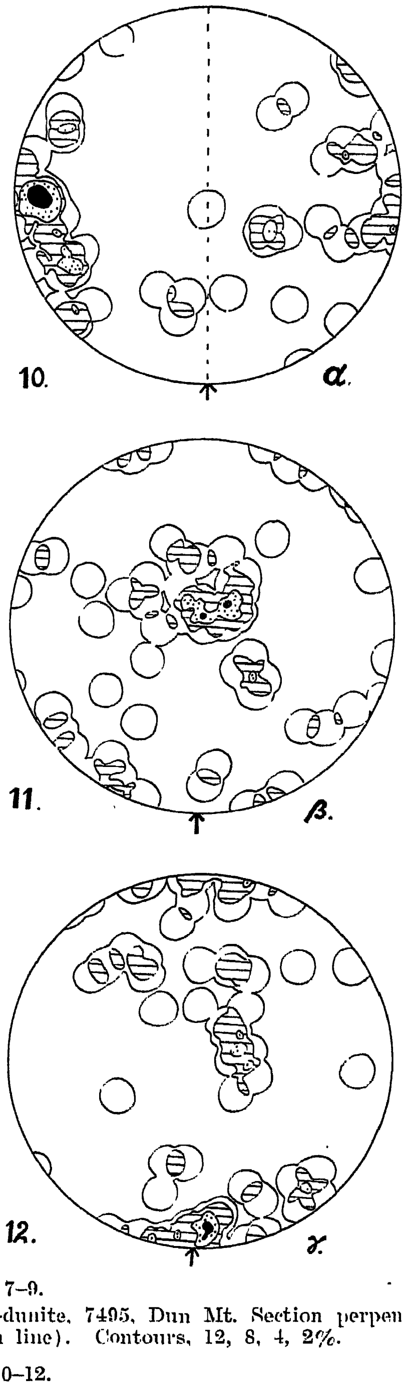
Figs. 1–3.

Olivine (50 grains) in mugearite, P.5561. Contours 8, 4, 2%. Broken line indicates the mean trend of elongation (γ) of plagioclase laths, within the measured section.

Figs. 4–6.

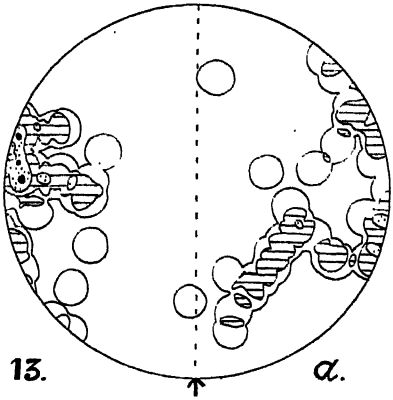
Olivine (50 grains) in hornblende-peridotite, Lugar sill. Contours 8, 4, 2%.



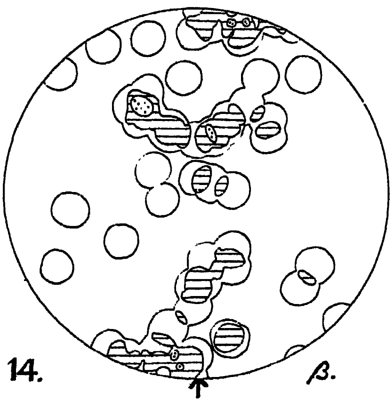


Figs. 7–9.
Olivine (50 grains) in banded chromite-dunite, 7495, Dun Mt. Section perpendicular to trend of bands (broken line). Contours, 12, 8, 4, 2%.

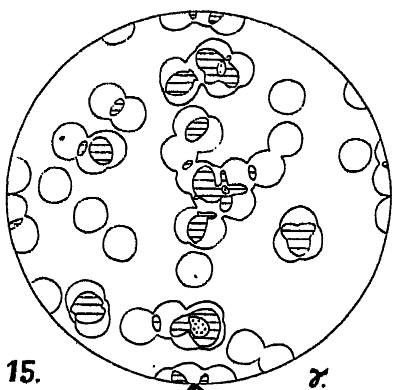
Figs. 10–12.
Olivine (50 grains) in banded chromite-dunite, 7494, Dun Mt. Section perpendicular to trend of bands (broken line). Contours, 12, 8, 4, 2%.



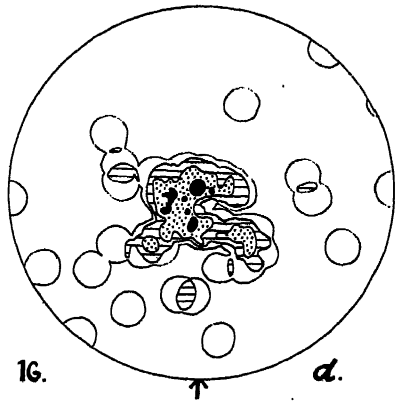
13. α.



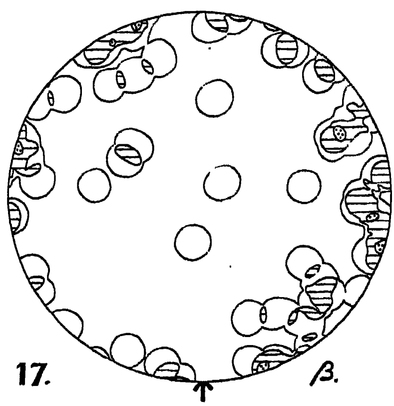
14. β.



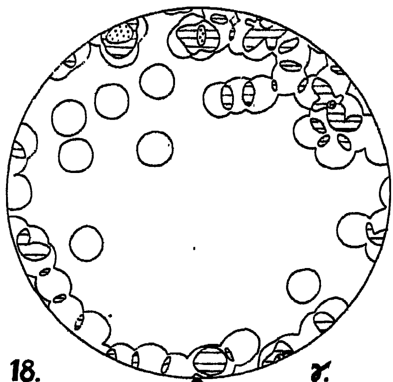
15. γ.



16. α.



17. β.



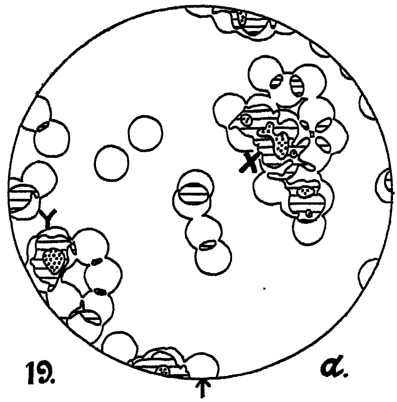
18. γ.

Figs. 13–15.

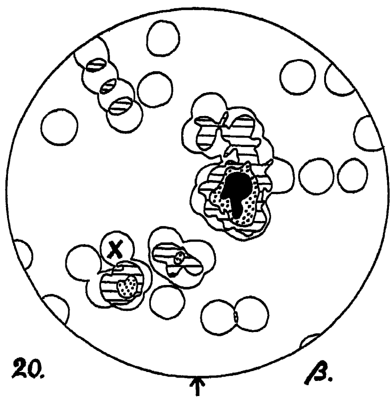
Olivine (50 grains) in banded picotite-dunite, 7496, Glen South of Alt a'Chaoich. Skye. Section perpendicular to trend of bands (broken line). Contours, 12, 8, 4, 2%.

Figs. 16–18.

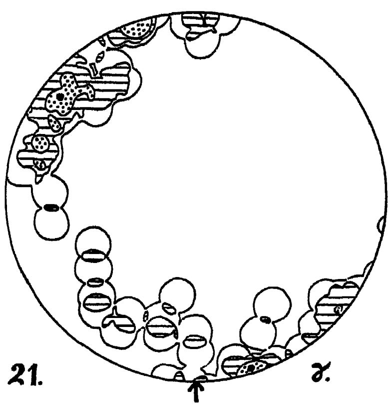
Olivine (50 grains) in fissile dunite, 7498, Glen south of Alt a'Chaoich. Skye. Section parallel to plane of fissility. Contours, 12, 8, 4, 2%.



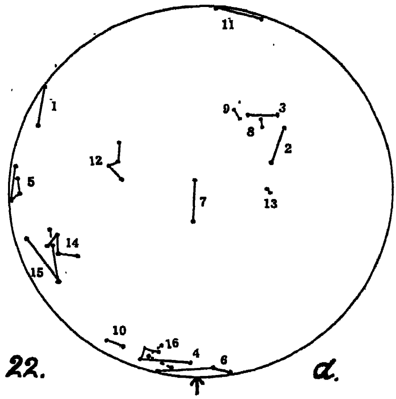
19. α.



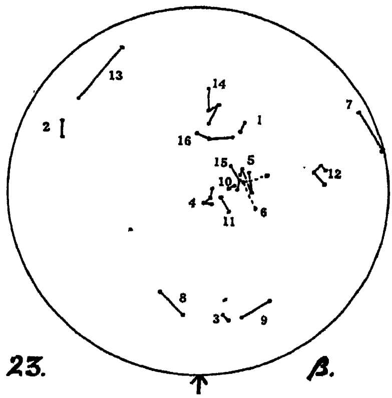
20. β.



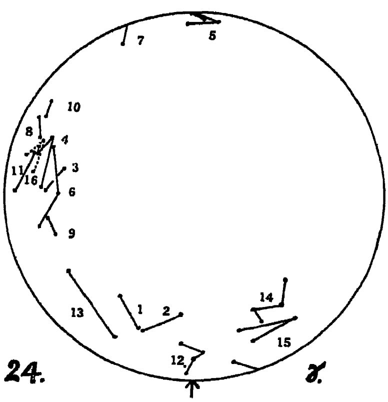
21. γ.



22. α.



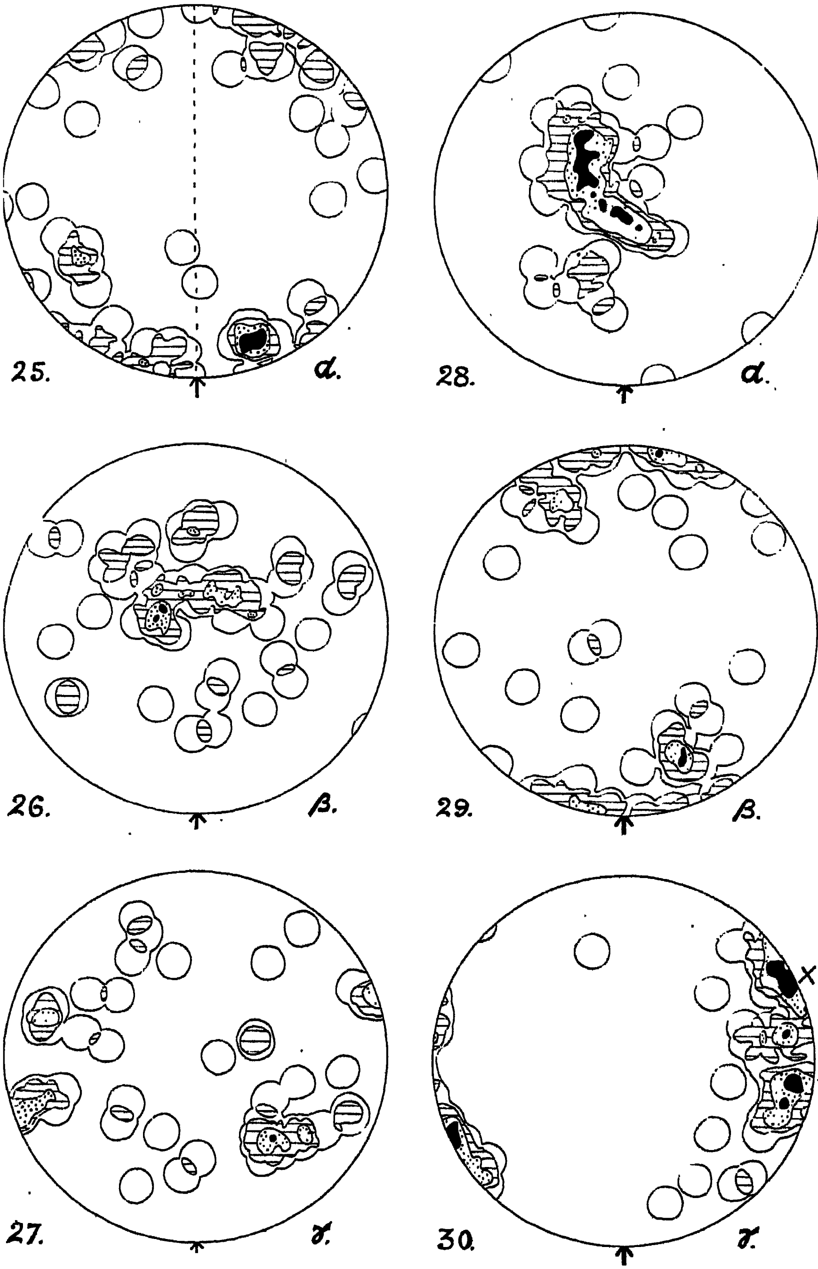
23. β.



24. γ.

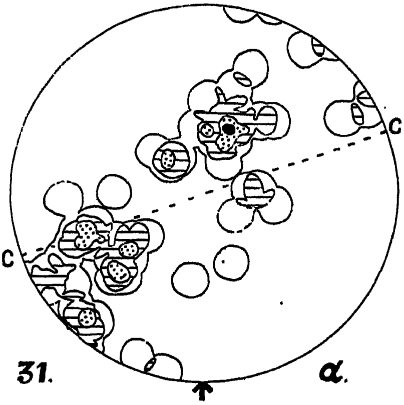
Figs. 19–21.
Olivine (50 grains) in slightly fissile dunite, 7493, Dun Mt. Section approximately parallel to fissility. Contours, 12, 8, 4, 2%; maximum concentration, 16% in Fig. 20.

Figs. 22–24.
Olivine (16 undulose grains) in fissile dunite, 7493, Dun Mt. Dots connected by straight lines represent observed positions of the indicatrix axis in any one crystal.

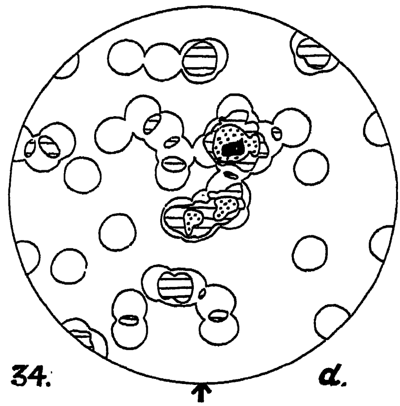


Figs. 25–27.
Olivine, (50 grains) in black olivine-rock, 7497, south of Abhuinn Fiadh-innis, Rum. Section perpendicular to the plane of fissility (broken line) and approximately perpendicular to lineation. Contours, 12, 8, 4, 2%.

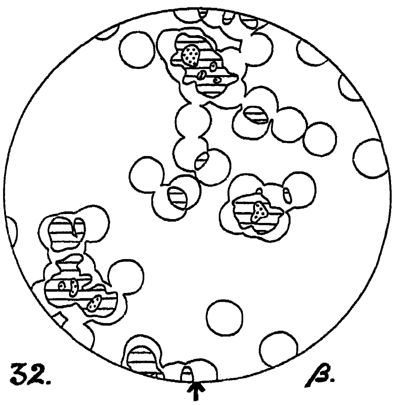
Figs. 28–30.
Olivine (50 grains) in harzburgite, 1380, Olivine Range, South Westland. Contours 12, 8, 4, 2%; maximum concentration 20% at X in Fig. 30; 16% in Fig. 28 and at Y in Fig. 30; 14% in Fig. 29.



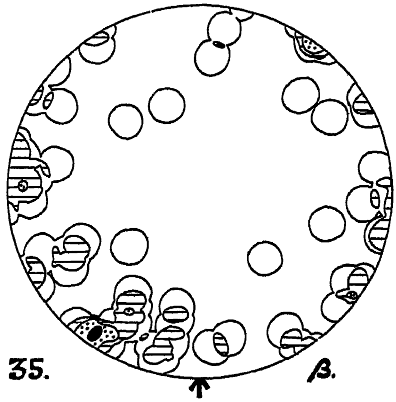
31. α.



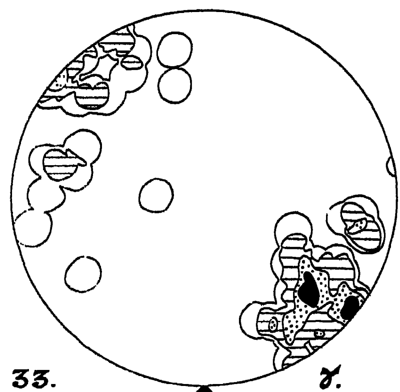
34. α.



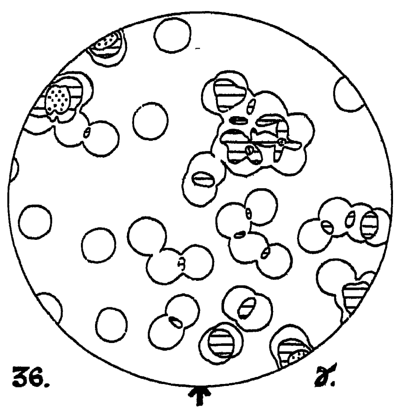
32. β.



35. β.



33. γ.



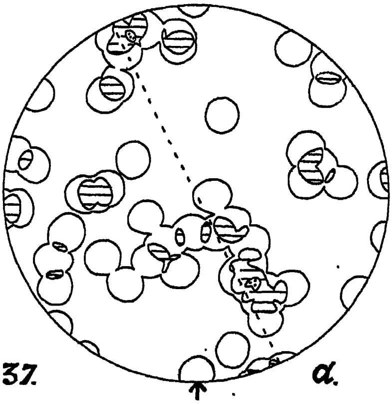
36. γ.

Figs. 31–33.

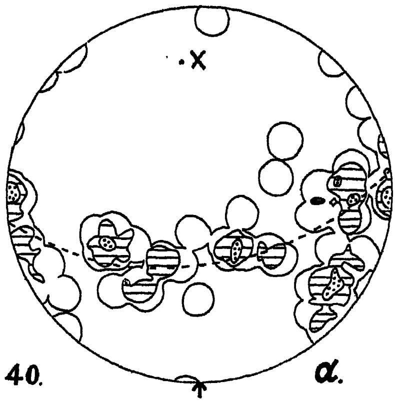
Olivine (50 grains) in dunite, 7505, Dun Mt. Nelson. Contours 12, 8, 4, 2%; maximum concentration, 16% in Fig. 33, *cc* = mean trend of most regular fractures.

Figs. 34–36.

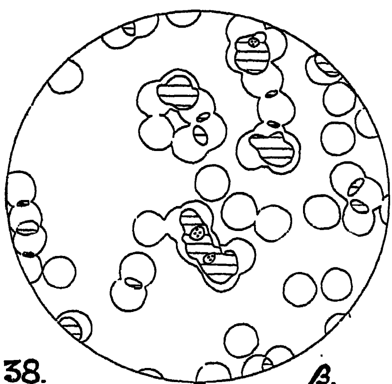
Olivine (50 grains) in dunite, 5308, near Bluff, Southland. Contours, 12, 8, 4, 2%.



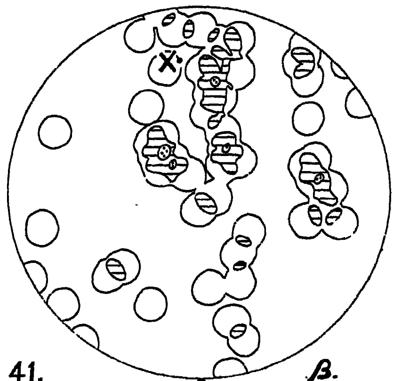
37. α.



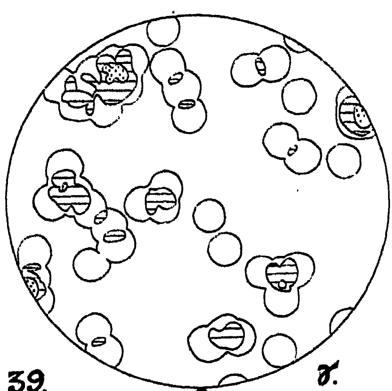
40. α.



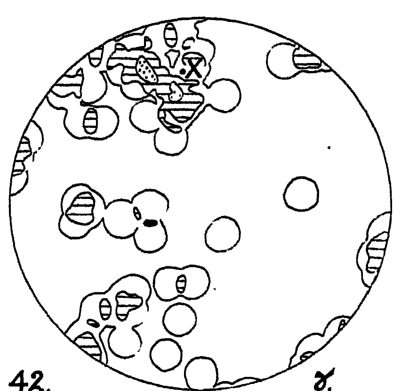
38. β.



41. β.



39. γ.



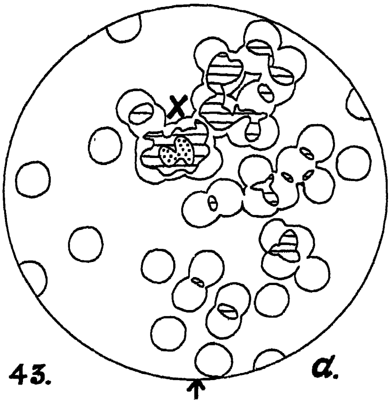
42. γ.

Figs. 37–39.

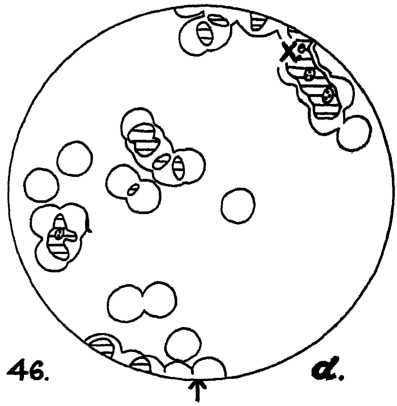
Olivine (50 grains) in cataclastic dunite (7491), Anita Bay, Milford Sound. Section perpendicular to plane of fissility (broken line). Contours, 8, 4, 2%.

Figs. 40–42.

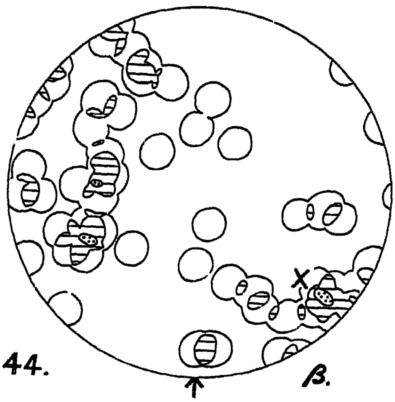
Olivine (50 grains) in nodule (7503) in basalt, Onepoto, Shoal Bay, Auckland. Contours, 8, 4, 2%. Maximum concentration in each case 10%. X = normal to the girdle (broken arc) of Fig. 40.



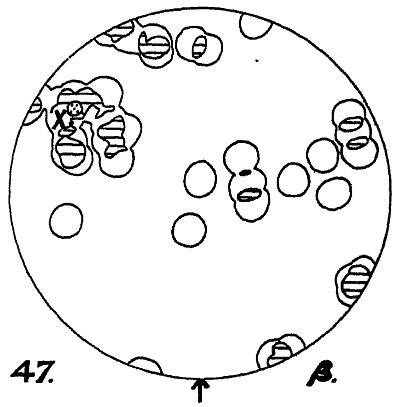
43. α.



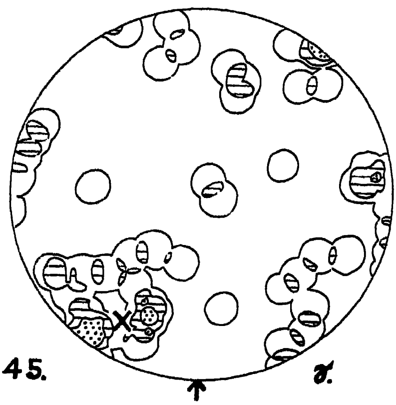
46. α.



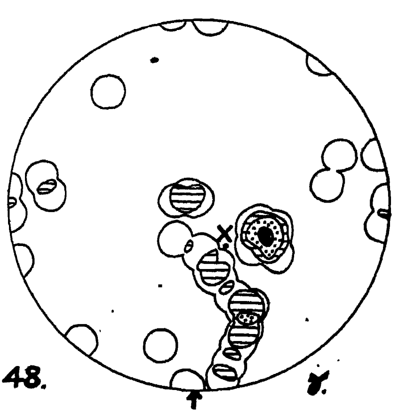
44. β.



47. β.



45. γ.



48. γ.

Figs. 43–45.
Olivine (50 grains) in nodule (5100) in Pliocene basalt, Kokonga, East Otago. Contours, 8, 4, 2%. Maximum concentration in each case, 10%.

Figs. 46–48.
Olivine (35 grains) in nodule (6655) in tachylite breccia, Kakanui, North-East Otago. Contours, 6, 4, 2, 1 points per 1% area.

of *Wegsamkeit*, as well as by rotation of pre-existing crystals into the same surfaces.

(2) Settling of olivine crystals under the influence of gravity as they separate from basic magma under static conditions also fails to produce preferred orientation of the olivine space-lattice (Figs. 4–6). (3) The megascopically conspicuous regular banding of certain fresh chromite-rich dunites is believed to have originated during flow of a "magma" in an advanced state of crystallisation. A feature of the fabric, constantly associated with banding, is preferred orientation of olivine governed by external form of grain, in that individual crystals tend to be elongated parallel to the banding. Therefore it is probable that this dimensional orientation and any consequent preferred orientation of the space-lattice are also determined by flow prior to complete solidification of the magma, rather than by movement and actual deformation of grains after the mass had become completely crystalline. A high degree of penetrative intergranular movement, such as would necessarily affect a largely crystalline dunite "magma" in process of injection as pictured by Bowen (1928, p. 167), would be expected to give rise to preferred orientation of grains according to their external form, and this would also involve orientation of space-lattice if the grains in question conformed uniformly to a well defined crystallographic habit. The usual habit of magnesian olivines is a prismatic form flattened normal to *b* (α) and elongated parallel to *c* (β). Laminar flow of the largely crystalline mass (with its lubricating interstitial liquid) along approximately plane surfaces (such as is indicated by the regular subparallel layers of the banded dunites) should give rise to a fabric the dominant feature of which would be a strong concentration of α-axes normal to the plane of flow (Figs. 7, 10, 13). A secondary feature, depending upon elongation of the crystals parallel to β, is the tendency for β to lie in the flow-surface even in grains for which α departs from the ideal orientation, so that the β-girdle perpendicular to the α-maximum is more clearly defined than is the γ-girdle. This condition is shown in Figs. 14, 15. The opposite tendency for the γ-girdle to be more pronounced than the β-girdle, shown by one of the two banded dunites from Dun Mt. (Figs. 8, 9), cannot be explained in terms of the above-described mechanism, and is attributed to later deformation.

(4) In the absence of visible banding in dunites poor in chromite, there is often no way of determining whether a simple orientation pattern, with a high concentration of α-axes and a fairly even spread of β and γ in the girdle normal to this, has originated by laminar flow prior to complete solidification of the magma or by deformation of the already solid mass. If magmatic flow is the controlling process, the space-lattice orientation should be accompanied by dimensional orientation of crystals with their long axes aligned in the surfaces of flow, and distinct fissility perpendicular to the α-maximum might be obvious in the hand-specimen. However, according to Ernst (*op. cit.*) dimensional orientation of olivines elongated at right angles to α is also conspicuous in schists whose fabric is of deformational origin.

(5) The fabrics of three Hebridean peridotites have been described in this paper. One (7496) is a banded type with a simple

fabric believed to have been determined by magmatic flow as discussed under (3) above. The second is a fissile non-banded rock (7498, Figs. 16–18) with a closely similar fabric which is therefore attributed to the same general process. The third rock (the black peridotite, 7497, from Rum) has a rather weakly defined fabric of quite a different type, the main features of which are an α-girdle normal to the plane of fissility, and a β-maximum perpendicular to the α-girdle and approximately parallel to a weak megascopic lineation (Figs. 25–27). This pattern is just what would be expected if, during flow of a largely but not completely crystalline mass, the crystals rotate with their long axes (β) aligned in the flow surface and normal to the direction of flow. The presence of a megascopic lineation strongly supports the possibility that such a mechanism has indeed controlled development of the fabric in this particular instance. Of the four Hebridean peridotites investigated by Phillips (1938) two have simple fabrics dominated by an α-maximum (Phillips, op. cit., 3, 4, 7, 8); in one other the α-maximum and β-γ-girdle are accompanied by a definite concentration of γ in the latter (Figs. 1, 2); the fourth fabric shows no preferred orientation of olivine (Fig. 6). Both Phillips' results and those of the writer may be explained on the assumption that the fabrics of Hebridean peridotites are due to flow of largely but not completely crystalline olivine-rich magmas, and have not been influenced to any extent by post-crystallisational deformation, of the rocks concerned. This is much the same conclusion as was arrived at by Phillips (op. cit., p. 134), except that the present writer would emphasise his opinion that deformation of crystals has played little or no part in development of the observed preferred orientation.

(6) The great steeply inclined dunite sills of Nelson and South Westland have been injected along zones of major dislocation during profound orogeny. The rocks concerned may therefore be expected to bear the imprint of post-crystallisational deformation superposed upon a fabric determined by flow prior to complete consolidation. The two effects will often be difficult to separate since both owe their origin to the same set of deforming forces acting upon the intrusive mass. (a) In specimens 1380 and 7505 there is strong preferred orientation of the olivine space-lattice but no recognisable dimensional orientation, so that the fabrics may be assumed with some confidence to have been determined mainly by deformation after complete solidification of the rocks in question. The orientation pattern of 1380 (Figs. 28–30) is marked by strong mutually perpendicular concentrations of α, β and γ respectively. The α-maximum is most pronounced and is somewhat elongated in a plane perpendicular to the mean trend of γ. If, as appears likely both on theoretical grounds and from fabric studies of Andreatta and of Ernst on olivine-tectonites, α tends to be oriented at right angles to the principal slip-plane of the fabric, then the direction in which γ is concentrated is the *b* fabric axis about which an incipient α-girdle is in process of development. This would point to β (crystal axis *c*) as the preferred glide-direction within a glide-plane (010). This conclusion is borne out by the fabric of 7505 (Figs. 31–33) in which the α-girdle is fully developed in a plane normal to a strong γ-maximum; in this

rock, too, micro-fractures inclined at high angles to the mean trend of γ (*b* fabric axis) are conspicuous and could be interpreted as *ac* fractures such as are commonly present in girdle-tectonites.

(b) The following sequence of events is suggested in explanation of the fabrics of 7494 (Figs. 10–12) and 7495 (Figs. 7–9) :—Laminar flow in the still partially liquid peridotite "magma" gives rise to a dimensional orientation of olivine crystals with which a strong concentration of α-axes normal to the flow-surfaces (s) may be correlated. As deformation of the intrusive mass continues after it has completely solidified, slip-movements develop principally in the original flow-surfaces, with which, moreover, the best marked crystallographic glide-plane (010) already coincides in many of the grains of olivine. However, before gliding can occur in any given grain it is necessary that the grain should rotate until the preferred glide-direction (β) is brought into approximate coincidence with the direction of slip-movement (*a* fabric axes) for the rock as a whole. Therefore one of the component movements accompanying the earliest stages of deformation of the solid rock is a rotation of both β and γ about the normal to s, with resultant concentration of β and γ in two mutually perpendicular directions in s. This condition is exemplified by Figs. 10–12, the fabric in this case being more weakly defined than is usual in West Coast peridotites. A further complication in the fabric would be introduced if there were several sets of slip-surfaces inclined at low angles to s, or if the latter were somewhat curved by external rotation about the *b* axis of the fabric. Both possibilities are commonly encountered in deformed rocks and would have the same effect upon the orientation of the olivine space-lattice—namely, spreading of the α-and β-maxima in the plane normal to the *b* axis of the fabric (direction of concentration of γ). A strongly developed fabric of this type is shown in Figs. 7–9, in which it will be noticed that whereas the γ-maximum is elongated within s, the β-maximum is much less distinct and is dispersed not only in s but also in the plane of elongation of the α-maximum.

(c) The strongly defined unique orientation pattern of Figs. 19–21 cannot be related to the megascopic fissility-planes of the rock in question on any such hypothesis as those put forward above. It would seem that the fissility is due to persistence of original surfaces of magmatic flow, and that the space-lattice orientation is the expression of a subsequent deformation under a new set of kinematic conditions. The unusually sharp γ-girdle is interpreted as a B-girdle such as is commonly developed in many tectonite fabrics, and the β-maximum on this assumption represents a concentration of β-axes parallel to B. Further interpretation is somewhat speculative, for more than one gliding mechanism could give rise to an orientation pattern of this one type, e.g.:

(1) glide-plane = (010) (i.e., $\perp \alpha$), glide-direction = γ;

(2) glide-plane = (100) (i.e., $\perp \gamma$), glide-direction = α.

On account of the sharpness of the γ-girdle and wide range of orientation of both α and β, gliding parallel to γ (theoretically the most probable glide-direction in olivine) in several crystallographic glide-planes, of which (010) is specially favoured, would appear the most likely orienting mechanism.

(7) In most peridotites having orientation patterns showing what is believed to be the influence of deformation subsequent to complete solidification [cf. (6) above], undulose extinction is conspicuous in the constituent grains of olivine. Since this property is considered to be an expression of combined flexural gliding and incipient rupture of the space-lattice, its origin is almost certainly bound up with the process of deformation by which the orientation pattern was imprinted upon the fabric as a whole. It has been suggested above that in many of the investigated rocks olivine grains, originally oriented by magmatic flow so as to bring α normal to the flow-surfaces (s), have subsequently rotated until β approaches the principal direction of slip for the deforming rock. As long as the opposing force of friction on the intergranular boundary surfaces did not exceed a limiting value, this rotation could be in the nature of differential movement of the individual grains. Once the friction exceeded this limiting value, intragranular flexural gliding on space-lattice surfaces inclined at high angles to s (the principal slip-surfaces of the rock fabric) could achieve the same result. For example, in the case of a grain with α approximately normal to s, flexural gliding on (001) with γ (crystal axis a) as glide-direction could rotate both β and γ within s. Deformation of the individual grains is therefore pictured as a complex process involving flexural gliding on (001) with γ as glide-direction, rupture and some differential movement on (100), and finally (when β is brought sufficiently close to the principal glide-direction for the fabric as a whole) translation-gliding on (010) parallel to β. It has long been recognised that some such process as flexural gliding, or a combination of gliding movements on two mutually perpendicular sets of crystallographic glide-planes, must be assumed in order to account for the high degree of preferred orientation of minerals that is commonly attained during comparatively slight deformation that cannot have involved extensive rotation of individual grains (e.g., cf. Schmidt, 1932, pp. 173–176; Eskola, 1939, pp. 297, 298, 304, 305). Finally attention is drawn to the single case (7493, Figs. 19–21) where gliding parallel to γ on various crystallographic planes, but especially on (010), is thought to have been the most influential process in development of the olivine fabric; as might be expected, undulose extinction is here more strikingly shown by the olivine grains than in any other rock investigated.

(8) When under high confining pressure a rock is strained beyond the elastic limit, it may deform plastically by combined plastic deformation of individual grains and recrystallisation through the agency of aqueous pore-solutions. In this way a cooling mass of peridotite, intimately penetrated by magmatic waters containing silica or carbon dioxide, may by continued deformation be converted to a schistose antigorite-serpentine. In the absence of water, however, recrystallisation of olivine or crystallisation of new minerals like serpentine or talc appears to be impossible. And when deformation advances beyond the stage where internal adjustment to the stress system can be achieved by movements on crystallographihc glide-planes and intergranular boundary surfaces, rupture of the olivine grains and differential movement of the fragments so produced become the essential factors in a deformation that may now be described as cataclastic. The ultimate product of a process of this sort is a fine-grained cataclastic dunite such as 7491, with a distinct

schistosity (*s*-planes of shearing) marked by alternation of bands of different grain-size and by dimensional parallelism of the elongated crystal fragments. Lack of preferred orientation of the olivine space-lattice is a characteristic feature of the fabric (Figs. 37–39).

(9) Mineralogically the olivine-nodules from New Zealand Tertiary and Pleistocene basalts are identical with lherzolites and harzburgites of plutonic origin. The constituent minerals include enstatite, chrome-diopside, picotite and chromite, none of which has been recognised in the enclosing basalts. In two of the three specimens used for fabric analysis (5100, 6655; Figs. 43–48) the orientation pattern, though very weak, conforms to a type here attributed to deformation of a solid rock, while the third fabric (7503; Figs. 40–42) with its pronounced α-girdle and absence of dimensional orientation of grains must have originated in a like manner. This conclusion is supported by prevalence of undulose extinction in all three cases. It is therefore suggested that all three nodules are fragments torn from masses of solid peridotite, which have formed under plutonic conditions but have never flowed in the form of injected bodies of largely crystallised peridotite magma. If these parent peridotites were formed as accumulations of early crystals separating from the primitive basaltic magma at sufficient depth for the conditions of temperature and pressure to be quite different from those obtaining during later crystallisation of the basalts themselves, the load of overlying rock and magma might well be sufficient to give rise to the weak deformation recorded in the fabric. The European nodules described by Ernst (*op. cit.*) on the other hand include rocks with strongly developed fabrics in which well developed girdles appear to indicate deformation of a more pronounced nature, especially in that the olivine of such rocks often shows strongly developed undulose extinction and translation-lamellae. The petrofabric evidence, taken in conjunction with the widespread occurrence of olivine-rich nodules in basalts in many parts of the world, points to deep-seated solid accumulations of olivine crystals and in some cases perhaps intrusions of peridotites as the source of the nodules in question. As Phillips has pointed out (*op. cit.*, p. 134) it is not necessary to assume the existence of a deep-seated metamorphic terrane as a source of olivine-nodules. Nor, however, can they be pictured as mere local aggregations of crystals separating from the basaltic magma just prior to eruption.

(10) The following characters of peridotite fabrics are considered as criteria of origin by flow in a largely but not wholly crystalline magma: *s*-planes marked by alternation of layers respectively rich and poor in chromite, or by parallel orientation of elongated olivine grains; concentration of α normal to *s*-surfaces of flow, and fairly even spread of β and γ within the plane of flow, the β-girdle sometimes being sharper than the γ-girdle; any concentration of β or γ within the plane of flow must be accompanied by microscopic or megascopic lineation due to dimensional parallelism of elongated grains as seen in sections parallel to the *s*-planes in question.

(11) Characteristic criteria of origin of a peridotite fabric by deformation of the solid rock include the following: presence of a complete or incomplete α-girdle at right angles to any visible flow

surfaces, accompanied by concentration of γ normal to the α-girdle and parallel to the b axis of the fabric; less commonly presence of simple mutually perpendicular maxima for α, β and γ respectively; occasionally development of a γ-girdle at right angles to a β-maximum which is parallel to b of the fabric; conspicuous undulose extinction and sometimes translation-lamellae normal to γ; cataclastic structure, schistosity due to shearing, dimensional parallelism of crystal fragments and lack of preferred orientation of the olivine space-lattice.

Acknowledgement.

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CORRIGENDA.

In Article I, "Octopodous Mollusca of New Zealand," by W. B. Benham.

The figures on p. 230 are nearly *twice the natural* size.

The figure in Pl. 18 is *nearly twice* the real size.

Those in Pl. 19 are *smaller* than the dimensions stated at foot.

In paper by J. Marwick, "Some Eocene Mollusca from New Zealand."

p. 272. In the synonymy of *Kurinuia areolata, Trigonia densicostata* should read *T. areolata.*

In paper by J. T. Salmon.

p. 377, the locality mentioned as Johnson's Hill should read Johnston's Hill.

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The Physical Characteristics of Meteors.

By R. A. McIntosh, F.R.A.S.

Communicated by C. G. G. Berry.

[*Read before the Wellington Branch, August 8, 1942; received by the Editor, July 27, 1942; issued separately, March, 1943.*]

The accumulation in New Zealand over the past fifteen years of more than 12,000 observations of individual meteors recorded by regular observers on a prearranged plan presents an opportunity for statistical studies of the physical characteristics not to be neglected.

In the years 1925-40 various observers of the Meteor Section of the New Zealand Astronomical Society have contributed to the total as follows:—

Observer.		Period.	Meteors.
Bateson, F. M.	(B)	1927-33	1,524
Fairbrother, S.	(F)	1935-38	851
Geddes, M.	(G)	1931-37	4,698
McIntosh, R. A.	(M)	1925-40	5,518
Others			218
			12,809

We have thus available for study the work of two experienced meteor observers (assuming that accuracy increases with numbers recorded) and others in various stages of proficiency.

The present paper has three principal objectives:—

(1) The determination of the average physical characteristics of a meteor, and the relations which can be established between them;

(2) An attempt to estimate from the divergencies revealed the accuracy to be expected in the recording of these features; and

(3) The effect of increasing experience upon the work of an observer.

With regard to (2) one cannot be certain that an examination of divergencies from the mean reveals the true state of affairs. The mean itself, based on the whole of the data of all the observers, irrespective of their experience, may not necessarily be the best representation of the truth, but it is the only standard available.

It should be noted that the data relate only to normal meteors recorded during the progress of routine observations. The hundreds of telescopic meteors and bright fireballs reported by persons not regular observers are not included in these statistics.

Magnitudes.—The distribution in brightness of the observed meteors is shown in Table 1, where the results are expressed in numbers per thousand meteors observed.

Table I.—Distribution of Magnitudes.

Observer.	Magn. > 1	1	2	3	4	5	6	Total.
F	13	42	153	367	243	158	22	851
G	32	75	146	248	297	156	45	4,698
M	59	153	183	186	187	177	53	5,518
Others ..	12	86	124	235	321	173	49	1,742
All	40	108	160	227	250	168	48	12,809

As is to be expected, more faint meteors are seen than bright ones, the number increasing inversely with the brightness. After the fourth magnitude, however, a marked falling off in numbers occurs, due probably to the majority of fainter meteors eluding observation. Some individual eccentricities are evident in the table, McIntosh overestimating the brightness of meteors in the middle magnitudes, while Fairbrother underestimated the brighter objects. The mean magnitude is 3.0.

The ratio of increase of numbers with decreasing brightness is steadier than one would expect in view of these personal equations. In Table II the ratio $\frac{Nm + 1}{Nm}$ is detailed, Nm representing the number of meteors of magnitude m.

TABLE II.—Ratio of Increase with Magnitude.

	Magnitude						Mean.
Obs.	0 – 1	1 – 2	2 – 3	3 – 4	4 – 5	5 – 6	0 – 4
F .	3.2	3.6	2.4	0.7	0.6	0.1	2.5
G ..	2.3	1.9	1.7	1.2	0.5	0.3	1.8
M .	2.6	1.2	1.0	1.0	0.9	0.3	1.5
All ..	2.7	1.5	1.4	1.1	0.7	0.1	1.7

It is uncertain at what stage of faintness the observer begins to miss seeing meteors. Down to the second magnitude the ratio is 2.1, which agrees closely with values found in other countries and with that shown by the naked-eye stars themselves (2.4). The ratio falls only gradually to the fourth magnitude, revealing that only a small proportion of these meteors are overlooked, but the rapid decline thereafter shows that only a few of the fainter meteors are seen. Portion of the decline in ratio may be real, arising from the fact that, as in the case of the stars, meteors are finite in number, but the greater portion of the decline must arise from the difficulty of detecting faint meteors in a large area of sky (generally about 50° square). The ratio between various magnitudes of telescopic meteors (to be dealt with in a later paper) confirms that the naked-eye records of the fainter meteors are not an indication of the true numbers present.

Assuming that the final line in Table I represents the truth (which is probably not the case), the average error in magnitude estimations can be determined. The deviations of the observers from the mean values are: F 4% error, G 2%, M 3%, others 2½%. From this it can be inferred that an experienced observer over or underestimates by one magnitude or more the brightness of three meteors in every hundred recorded. The mean deviations in ratio of increase are more consistent, being: F 0.7, G 0.3, M 0.2.

The increase in the number of faint meteors detected with increasing experience is worthy of comment. In Table III the totals of fifth and sixth magnitude meteors recorded are tabulated and smoothed for McIntosh's records. The smoothing formula used is $X_s = \frac{1}{4}(X_{r-1} + 2X + X_{r+1})$. A steady increase in numbers with increasing experience to a maximum after five years' experience is revealed. The small drop in numbers in 1936 coincided with the observer's removal from a relatively dark suburb to a position where the glare of city lights caused considerable sky glow.

TABLE III.—Number of Fifth and Sixth Magnitude Meteors recorded in every thousand meteors seen.

Year.	Number. 5th + 6th Mag.	Number. Smoothed.
1919-21	30	(30)
1925	6	18
1926	28	28
1927	52	74
1928	165	113
1929	236	236
1930	306	270
1931	232	257
1932	257	241
1933	217	241
1934	276	260
1935	273	271
1936	263	252
1938	209	250
1940	318	(318)

Dr. E. Opik (*Harvard Annals*, 105, p. 562) has applied to estimations of meteor magnitudes the criterion better known for its use in star counts—statistical photometry. Briefly, the magnitudes are smoothed to eliminate the " decimal equation " arising from the fact that meteor magnitudes are recorded only as whole magnitudes. The limiting magnitudes of certain fixed percentages of the total meteors are determined. If an observer is consistent in his magnitude determinations the limiting magnitudes for any percentage should lie close to those determined at other epochs.

In Table IV the limiting magnitudes for 10, 30, 50, 70 and 90 per cent. of the total meteors are given for each observer in each year.

TABLE IV.—Limiting Magnitudes of Fixed Percentages of Meteors.

Obs.	Year.	10%	30%	50%	70%	90%
F	1935	2.08	3.17	3.88	4.60	5.43
	1936	2.00	3.22	3.97	4.73	5.53
	1938	1.60	2.64	3.19	3.76	4.62
	Mean	1.89	3.01	3.68	4.36	5.19
	Mean Deviation	0.17	0.26	0.29	0.66	0.38
G	1931	1.18	2.91	3.87	4.74	5.58
	1932	1.24	2.98	3.88	4.68	5.53
	1933	1.90	3.25	3.99	4.70	5.56
	1934	2.14	3.49	4.24	4.93	5.63
	1935	2.14	3.26	3.96	4.69	5.55
	1936	1.90	3.23	3.98	4.67	5.54
	1937	1.68	3.12	3.88	4.62	5.38
	Mean	1.74	3.18	3.97	4.72	5.54
	Mean Deviation	0.27	0.13	0.09	0.07	0.05
M .. .	1925-28	0.65	2.55	3.52	4.52	5.50
	1929	0.70	2.50	3.62	4.59	5.58
	1930	0.74	2.75	3.95	4.87	5.68
	1931	0.34	2.12	3.34	4.53	5.60
	1932	0.25	2.46	3.68	4.70	5.62
	1933	0.75	2.54	3.58	4.55	5.55
	1934	0.93	2.88	3.92	4.86	5.63
	1935	0.83	2.62	3.87	4.81	5.64
	1936	0.65	2.56	3.70	4.63	5.64
	1938	0.20	2.14	3.46	4.53	5.52
	Mean	0.65	2.55	3.70	4.68	5.60
	Mean Deviation	0.15	0.04	0.02	0.01	0.00

The fact emerges that the two experienced observers remain remarkably consistent in their estimations of brightness, as is shown by the small deviations, while those of Fairbrother are very erratic, the mean deviation in his case even increasing with the percentage when, from the nature of the analysis, it should decrease to a small residual at 70% and 90%.

Inspection of the table reveals that while the observers remain consistent in their estimations (with the exception of Fairbrother) the data for one observer do not agree with those of another. While McIntosh finds, for example, 30% of his total meteors equalling or greater than magnitude 2.55, Geddes needs to include meteors down to magnitude 3.18 to reach a similar percentage. While portion of this discrepancy is due to over-estimation in the middle magnitudes by McIntosh (as mentioned earlier), the figures also reveal that Geddes sees more faint meteors than McIntosh. As the former has always observed from country districts and the latter in the suburbs of Auckland the difference may possibly arise from sky glare. From a consideration of meteor rates it has already been shown (*Popular Astronomy* 46, 9, 516; 1938, Nov.) that, for every ten meteors seen by Geddes, McIntosh can expect to see only seven, an indication of the value of dark skies for meteor observing.

Durations.—The numbers of meteors of various durations per thousand meteors seen are shown in Table V, which reveals the short duration of the meteor's flight, more than half the observed meteors (54.2%) having durations between 0.4 and 0.6 seconds inclusive, while only 3% endure for more than one second. In this short interval the observer must record the numerous physical details studied in this paper.

TABLE V.—Distribution of Durations.

Obs.	Duration in seconds. 0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	> 1.0
F ..	14	156	244	136	202	50	44	45	7	68	36
G ..	18	92	127	218	207	144	76	44	12	20	45
M ..	16	52	192	256	194	102	71	50	4	41	21
All ..	16	76	174	231	199	112	70	47	7	36	31

While it is relatively easy for an observer to distinguish between short durations it becomes more difficult to distinguish between longer ones, such as 0.9 and 1.0 secs. In such cases the observers normally have preferred the whole number, which accounts for the excess recorded as of duration 1.0 secs. The mean residuals are: F 3.4%; G 1.5%; M 0.9%; or a mean for the three observers of 1.9%.

Length of Flight.—The New Zealand observers draw the paths of observed meteors on gnomonic maps of the sky. The lengths of these paths have been measured by reference to a standard scale, instead of by the more accurate graticule superimposed on the maps. There is therefore a systematic error in the measurement of paths increasing with distance from the centre of projection. Path measurements are exact if they occur near the centre of the map, while others near the edge may be several degrees in error. Assuming even dis-

tribution on the maps, the average measure should be 5% greater than the truth; which amounts in the average meteor to an excess of ½°, less than the error of observation.

TABLE VI.—Distribution of Path Lengths.

Obs.	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°
B	1	0	94	110	143	219	64	43	94	14	130
F	0	2	9	32	65	71	105	100	119	70	75
G	6	10	40	99	146	188	157	104	74	47	34
M	4	6	29	51	72	85	79	85	61	60	59
All	4	7	32	69	100	125	110	92	75	55	54

Obs.	11°	12°	13°	14°	15°	16°	17°	18°	19°	20°	> 20°
B	0	33	0	0	33	0	0	0	0	1	0
F	67	56	41	27	29	23	18	20	12	12	45
G	16	16	11	9	3	3	3	3	3	.2	20
M	52	48	32	30	34	30	26	22	13	17	96
All	38	37	24	21	23	19	17	14	10	11	61

The distribution of path lengths per thousand meteors seen reveals some variations. Whereas Bateson and Geddes record very few meteors with paths greater than 10°, with very large numbers about the mean, Fairbrother's and McIntosh's records reveal smaller numbers about the average and more long-pathed meteors. The mean values for the various observers are as follows: B 6.1°, F 9.4°, G 5.9°, M 10.3°.

The figures exhibit a well-marked personal equation. As the two experienced observers differ by 4.4° in their mean values, and the less experienced observers also are grouped in two classes, there is no way of determining where the true mean lies. The only independent value for mean length of path available is that of I. Astapowitsch (*Mirovedenie* No. 24, 1929 May), who finds a mean length of 8.3°, only 0.4° from the New Zealand value. It would therefore appear that Bateson and Geddes consistently plot their paths too short and Fairbrother and McIntosh record theirs too long. The deviations of the various observers from the mean amount to: B 3.4%; F 1.7%; G 1.9%; M 1.3%.

Colours.—The statistics concerning the colours of meteors present some interesting features. In the first place Table VII reveals that colour in meteors is surprisingly rare, less than one meteor in every four exhibiting any deviation from whiteness. In the fainter objects, however, colour cannot be observed, and therefore 5th and 6th magnitude meteors are excluded from this data.

TABLE VII.—Colours of Meteors.

Obs.	Red.	Orange.	Yellow.	Green.	Blue.	White.	Per cent. Coloured.
F	64	17	42	3	16	860	14.0
G	79	30	58	12	36	786	21.4
M	66	39	20	26	94	754	24.6
Others	66	13	14	39	22	845	15.5
All	71	31	35	21	57	784	21.6

Once again the value of experience is seen, the less-experienced observers failing to notice one coloured meteor in every four. The only outstanding variation between observers' records is that McIntosh records many more blue meteors than the others. This may arise from the fact that McIntosh records in this colour meteors no bluer than Sirius, while the others apparently class such meteors as white and reserve the blue classification for objects more prominently coloured. The mean deviations of the various observers are: F 2.7%; G 1.1%; M 1.7%; others 2.6%.

Relations between Features.—In the tabulations which follow, revealing the inter-relations between various physical features of the observed meteors, it has been considered advisable to draw a distinction between normal meteors (with durations not exceeding one second) and all meteors recorded, irrespective of their duration.

Magnitude-Duration.—In Tables VIII and IX are shown the dependence between brightness and duration for all meteors and for normal objects. In both tables it is seen that greater brightness in a meteor results in a longer duration of visibility. The only difference between the normal objects and the total meteors observed is that the elimination of the abnormal objects in Table IX not only numerically smoothes the relationship but also considerably reduces the average durations, indicating that the abnormal meteors excluded are to be found among the brighter objects.

TABLE VIII.—Relation between Magnitude and Duration.

(All Meteors)

Obs.	Magnitude. > 1	1	2	3	4	5	6	All.
F	1.120s	1.180s	0.644s	0.430s	0.394s	0.413s	0.490s	0.492s
G	0.924	0.552	0.543	0.512	0.497	0.459	0.420	0.510
M	0.764	0.607	0.504	0.477	0.473	0.417	0.398	0.50C
All	0.837	0.608	0.531	0.488	0.480	0.433	0.411	0.506

TABLE IX.—Relation between Magnitude and Duration.

(Normal Meteors: Durations < 1.1s)

Obs.	Magnitude. > 1	1	2	3	4	5	6	All.
F	0.867s	0.758s	0.603s	0.425s	0.378s	0.407s	0.440s	0.447s
G	0.505	0.468	0.472	0.480	0.477	0.444	0.397	0.468
M	0.624	0.565	0.481	0.463	0.454	0.410	0.393	0.475
All	0.593	0.541	0.485	0.466	0.461	0.427	0.399	0.470

Remembering that durations are recorded only to the nearest tenth of a second, it is gratifying to find, when large numbers of meteors are considered, that the mean durations of experienced observers vary by only 1/50th to 1/100th of a second. The respective divergencies are: F 0.102s; G 0.022s; M 0.011s; or an average divergence of only 0.072s for normal meteors.

Magnitude-Distance.—When magnitude is related to length of path a similar phenomenon is exhibited, for in both classes of meteor (Tables X and XI) the brighter objects invariably cover the longer paths in the sky, although once again the removal of abnormal meteors (Table XI) smoothes the data and reduces it to lower values.

TABLE X.—Relation between Magnitude and Length of Path.
(All Meteors)

Obs.	Magnitude. > 1	1	2	3	4	5	6	All.
F ..	20.8°	17.11°	12.9°	9.2°	9.0°	7.7°	7.3°	9.9°
G ..	20.9	8.3	6.9	6.0	5.7	5.5	6.4	6.4
M ..	20.4	16.0	11.4	9.6	8.7	7.4	6.4	10.6
All ..	20.4	14.4	9.6	8.1	7.3	6.8	6.4	9.1

TABLE XI.—Relation between Magnitude and Length of Path.
(Normal Meteors)

Obs.	Magnitude. > 1	1	2	3	4	5	6	All.
F ..	21.8°	14.6°	12.2°	9.0°	8.7°	7.5°	7.3°	9.4°
G ..	12.1	7.8	6.6	5.4	5.5	5.4	5.4	5.9
M ..	19.2	15.4	11.2	9.5	8.6	7.3	6.2	10.3
All ..	18.2	13.8	10.0	7.8	7.1	7.0	6.0	8.7

It is to be expected, when the majority of meteors move at velocities close to the mean, that those which have the greatest durations (i.e., the brighter ones) should require longer paths. The observers' divergencies from the mean are: F 1.5°; G 3.1°; M 1.9°; or a mean divergence of 1.9°.

Colour-Duration.—Assuming that meteors of all compositions enter the atmosphere at about the same velocity and become visible about the same height, we must conclude that those which burn out more quickly are composed of the most inflammable substances.

In Tables XII and XIII meteors below magnitude 4 are excluded (as in Table VII). The most important fact revealed is that meteors possessing perceptible colour have greater durations than those for which no colour was discerned. In both normal and abnormal classes it appears that yellow and orange meteors have the shortest durations of those exhibiting colour, and therefore represent the more volatile substances, while blue and red are in an intermediate group, with green objects possessing the greatest durations of all, and therefore probably representing the type of meteor most resistant to combustion.

TABLE XII.—Relation between Colour and Duration.
(All Meteors)

Obs.	Red.	Orange.	Yellow.	Green.	Blue.	White.
F ..	0.965s	1.320s	1.000s	1.750s	0.654s	0.456s
G ..	0.718	0.753	0.666	0.807	0.635	0.486
M ..	0.602	0.497	0.517	0.698	0.722	0.520
All ..	0.687	0.630	0.632	0.743	0.698	0.497

TABLE XIII.—Relation between Colour and Duration.
(Normal Meteors.)

Obs.	Red.	Orange.	Yellow.	Green.	Blue.	White.
F ..	0.754s	0.740s	0.666s	0.000s	0.590s	0.488s
G	0.570	0.545	0.495	0.552	0.471	0.466
M	0.543	0.460	0.501	0.643	0.605	0.496
All	0.589	0.497	0.496	0.622	0.570	0.475

It is rather surprising to find the red meteors unrelated to the yellow and orange groups and, in mean duration, more closely allied to the blue objects. The point must be made, however, that the majority of blue meteors recorded were no bluer than Sirius, and therefore closely approach the white class, which posseses the shortest durations. Assuming that the near-white blue meteors have short durations similar to the white meteors, it is possible that the true blue objects possess durations much greater than shown in the tables, and are, in fact, allied with the green objects.

The differences between the observers' means and the mean of the combined observations are as follows: F 0.049s; G 0.042s; M 0.028s; all 0.04secs.

Remarkable Meteors.—Meteors are classified as remarkable for a number of reasons. They may appear stationary in the sky or to have curved paths (which denote special positions relative to the observer) or they may exhibit physical abnormalities such as unusual nuclei, variable brightness, halting motion, irregular paths, or leave unusual or long-enduring trains.

The frequency of occurrence of such phenomena per thousand meteors is shown in Table XIV, where the most interesting feature is found to be the comparative rarity of such abnormalities, only 32 meteors in every thousand seen exhibiting peculiarities.

TABLE XIV.—Remarkable Meteors.

Obs.	Stationary.	Remarkable Nuclei.	Variable Magnitude.	Irregular Path.	Halting Motion.	Curved Path.	Trains Unusual	Trains > 2sec.	Abnormal.
E ..	4	0	0	0	2	8	0	5	16
F ..	0	0	3	2	0	1	0	3	10
G .	4	1	2	12	1	7	1	9	38
M ..	3	5	8	4	1	2	1	11	35
All ..	3	2	5	7	1	5	1	9	32

Here again the value of experience in observing is to be noted. The final column of the table reveals that the more experienced observers see twice as many remarkable objects as the others.

Trained Meteors.—When we come to examine those meteors which leave behind them luminescent trains of light, we find that such trains are comparatively rare, only 126 meteors in every thousand leaving streaks. The magnitude distribution of train-forming meteors is shown in Table XV.

TABLE XV.—Magnitudes of Train-forming Meteors.

Obs.	>1	1	2	3	4	5	6	Total.
			Magnitude.					
F ..	49	166	313	337	80	55	0	188
G ..	147	187	241	203	147	61	12	91
M ..	222	379	204	102	70	18	5	142
All ..	178	293	229	161	95	36	6	126

Trained meteors are on the average two magnitudes brighter than other meteors, the mean magnitudes being respectively 0.9 and 3.2.

The ratio of increase of numbers with decreasing brightness, shown in Table XVI, reveals the same trend as in ordinary meteors (Table II) but the ratios are only half as great and decline more rapidly.

TABLE XVI.—Ratio of Numbers to Magnitude.

Obs.	Magn. 0–1	1–2	2–3	3–4	4–5	5–6
F	3.4	1.9	1.1	0.2	0.7	–
G	1.3	1.3	0.8	0.7	0.4	0.2
M	1.7	0.5	0.5	0.7	0.3	0.3
All	1.6	0.8	0.7	0.6	0.4	0.2

Table XVII reveals the number of coloured meteors possessing trains per thousand observed meteors.

TABLE XVII.—Colours of Train-forming Meteors.

Obs.	Red.	Orange.	Yellow.	Green.	Blue.	White.	Total Coloured.
F ..	34	16	5	4	7	938	62
G ..	122	79	107	25	87	580	420
M ..	45	25	15	61	133	721	280
All ..	55	32	29	40	95	749	250

There is a slightly higher percentage coloured (25%) than in the case of ordinary meteors (21.6%). The distribution among the individual colours, however, is very similar in both groups, and it can be deduced that colour itself is not a factor in causing trains. The only exception between the two groups is that whereas blue shows a high percentage among ordinary meteors it occurs very rarely among trained objects.

The mean durations of train-forming meteors and of the trains they leave are as follows:—

Obs.	Meteors.	Trains.
F	0.816s	1.189s
G	0.632	1.921
M	0.733	1.433
All	0.721s	1.621s

The train generally lasts twice as long as the meteor creating it. and that meteor itself lasts 50% longer than the ordinary object

The mean length of path of the train-forming meteor, according to the various observers, is as follows:—

F 14.0°; G 10.3°; M 16.0°; All 14.5°.

which compares with a length of 9.4° for the ordinary meteor

Characteristics of Average Meteors.—Finally it may be of interest to summarise the characteristics of the average normal meteor (both trained and untrained) as revealed from the New Zealand data:—

	Untrained.	Trained
Magnitude	3.4	0 9
Duration (seconds)	0.434	0.721
Path length (degrees)	7.7	14 5
Coloured (percentage)	21.6	25.0

In the earlier tables these characteristics have slightly different values (there relating to all recorded meteors), but in the above table the comparisons are between trained and untrained meteors.

My thanks are due to the observing members of the Meteor Section whose labours have made this paper possible, and especially to Messrs. Fairbrother and Geddes, who extracted preliminary statistics from their own observations as they were secured.

Upper Winds at Little America on November 29, 1929.

By Squadron Leader C. E. PALMER, Meteorological Branch, R.N.Z.A.F.

[*Read before the Wellington Branch, September 16, 1942; received by the Editor, September 17, 1942; issued separately, March, 1943.*]

SUMMARY: This paper deals with the upper wind conditions on the 28th-30th November, 1929, as shown by pilot balloon soundings at Little America. From the soundings it is deduced that for at least a week a warm anticyclone extending from the surface to beyond 5 km. was located over Antarctica, and it is suggested that such anticyclones are more frequent in the area than the theory of the polar vortex would lead one to suppose.

In 1893, taking the distribution of mean pressure at the earth's surface and assuming values for the mean lapse rate of temperature, Teisserenc de Bort constructed pressure maps for levels at various heights in the upper air. From these and similar maps it may be inferred that the average circulation in the upper part of the troposphere is controlled by two gigantic cyclones, centred one at each pole (the so-called polar cyclones or polar vortices). The circulation in the Southern Hemisphere appears to be simpler than that in the Northern, and this was, and still is, attributed to the more uniform distribution of land and sea south of the equator. The Southern circulation, then, should be more representative of average conditions, such as would exist on a globe uniformly covered by water. If, as it seems reasonable to assume, the winds in extra-tropical regions are on the average geostrophic, the maps show that between about 30° S. and the Antarctic coast westerly winds must prevail throughout the atmosphere from the surface to the tropopause. This is partly confirmed by surface and upper wind observations that have been made in South America, South Africa, Australia and New Zealand, since the construction of the original maps. But observations on the Antarctic Continent have shown that there the surface winds are predominantly easterly or south-easterly in direction, at all events near and on the coast—i.e., that the surface circulation is controlled, not by a polar depression, but by an anticyclone, co-extensive with the continent. However, most meteorologists assume that this anticyclone is shallow and that, at no great height above the continent, it is replaced by the inner portions of the polar vortex—that here also the upper winds are predominantly westerly.

It is obvious from its derivation that the idea of a "polar vortex" is an abstraction, adequate, perhaps, as a summary of average conditions, but misleading if applied to the analysis of individual synoptic situations in the far south. To find, by the manipulation of mean values, that the Antarctic anticyclone is on the average a shallow pressure feature may be justified, but to

deduce from this that all easterly, south-easterly and southerly winds, and in particular the blizzards, are "katabatic" or are shallow surface flows is to obtain a result that it really beyond the capacity of climatological methods.

In a recent publication (5) I have shown that easterly blizzards may occur in the South Indian Ocean at some distance off the Antarctic coast, that these easterlies are similar to those described by Meinardus at the "Gauss" winter station on the coast (3), and that they are not "katabatic flows," but are essential parts of vigorous cyclonic circulations in the South Indian Ocean. It is probable, of course, that these easterlies are shallow and give place to northerlies or north-westerlies at upper levels, since an occlusion is usually associated with the depression. But it is pertinent to ask whether the easterlies are shallow at some distance south of the low-pressure centre, say, at 80° S. South of the Indian Ocean there is no information which would enable us to answer this question, but as depressions are frequently found at the mouth of the Ross Sea or in the sea itself, a clue, at least, to the answer may be found in the beautiful series of pilot balloon runs made in 1929 and 1934 at Little America (Latitude 78° 34′ S.). (2).

Analysis of these pilot balloon ascents shows that winds from an easterly quarter are surprisingly frequent at all levels up to

Percentage frequencies of different wind directions from Pilot Balloon data. (Combined data. Years 1929 and 1934.)

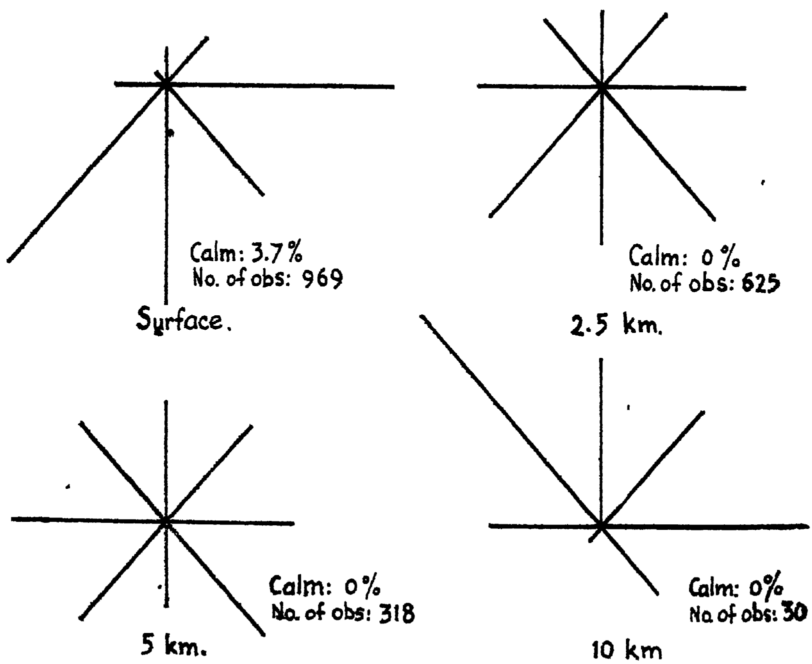


FIGURE 1.

10 kilometres. The frequencies (as given by Grimminger) of different wind directions at the surface, 2.5 km., 5 km. and 10 km., from the combined data for 1929 and 1934 are summarised in Figure 1 in the form of wind roses. The rose for 5 km., especially, is worth study. It shows that at this level winds from all directions are approximately equal in frequency. We may suspect from this alone that deep easterlies—i.e., easterlies extending from the surface up to or beyond 5 km.—are far more frequent than would be expected from the theory of the polar vortex. The suspicion has been confirmed in the following manner: For the 22 complete months (1929-30 and 1934-35) for which pilot balloon flights are available I have taken the number of days when at least one flight reached 5 km.; then, if a deep easterly be defined as a day on which, from the surface geostrophic level to 5 km., the wind remained between N.N.E. and S.S.E., these deep easterlies amounted to 38% of the 5 km. flight-days. If the flights reaching 3 km. or more be treated in the same way it will be found that deep easterlies amounted to 44% of the 3km. flight-days. It may be contended that 3 or 5 km. flights are more likely on those days when deep easterlies prevail. Fortunately Grimminger (1) has made an analysis of the conditions preceding and accompanying "clear" periods, when long flights are most likely. He defines a "clear" period as one during which there was not more than five-tenths of upper clouds, not more than two-tenths of middle clouds and not more than one-tenth of low clouds. Figure 2 shows a wind rose giving the percentage frequencies of winds from different directions at 5 km. during "clear" periods.

Comparison of Figures 1 and 2 and perusal of Grimminger's tables reveals that "clear" periods are probably dependent on the direction of the wind in the lowest layers; winds off the ice, that is, with a southerly component, tend to be free of low cloud. The 5 km. winds are still more or less equally distributed.

Little insight into deep easterlies can be gained by a study of frequencies alone. Before any interpretation of the upper

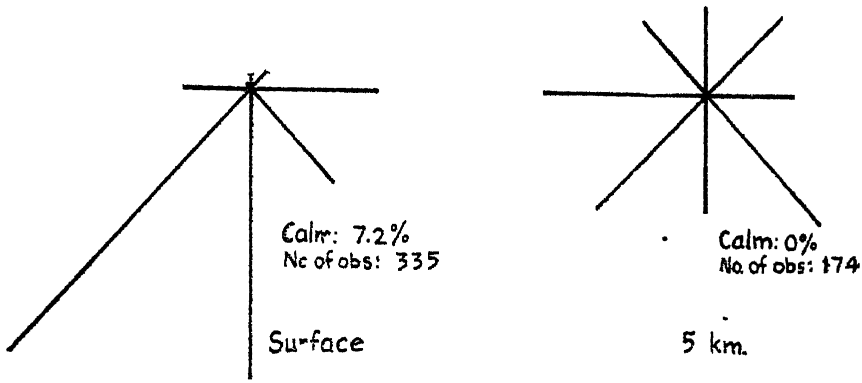


FIGURE 2.

circulation is possible a detailed investigation of individual flights and the relative synoptic situations would have to be carried out. Unfortunately, synoptic material for the periods covered by the expeditions is almost entirely lacking, and the New Zealand and Australian reports that are available are of too poor a quality to serve for reliable frontal analysis. For the period November-December, 1929, however, I have been able to obtain a private weather log maintained by Captain W. W. Stuart on board the whaling ship "Southern Princess" in the Ross Sea. My best thanks are due to Captain Stuart for permission to extract information from this log and to use it in the analyses shown in Figures 5, 6 and 7. It should be understood that these analyses are probably correct only in broad outline, representing the best means of explaining the changes in the meteorological elements at Little America, at the "Southern Princess" (for which readings of the barometer and thermometer at four-hour intervals are given in the log) and at stations in New Zealand keeping autographic records at that time. The analyses provide a background, as it were, for a different and more searching method of attack, recently developed by Rossby and his pupils. (4, 6.)

To illustrate this method, which should be of very great value in future Antarctic studies, I have chosen the deep easterlies that prevailed at Little America during the period 00.00 G.M.T. 29th November, 1929, to 00.00 G.M.T. 1st December, 1929, as shown by the two remarkable balloon soundings at 09.42 G.M.T. and 15.52 G.M.T. on the 29th. The hodograph for the former of these flights is shown in Figure 3. From the hodograph it is evident that the geostrophic wind at the top of the friction layer (given by the Ekman spiral) was 4.7 m/s from 68°; that between that level and 1.7 km. the wind shear vector was directed approximately from north to south, indicating a similar trend in the mean isotherms and, consequently, that the air in the lowest 1.7km. was warmer to the east of the station than to the west; that from

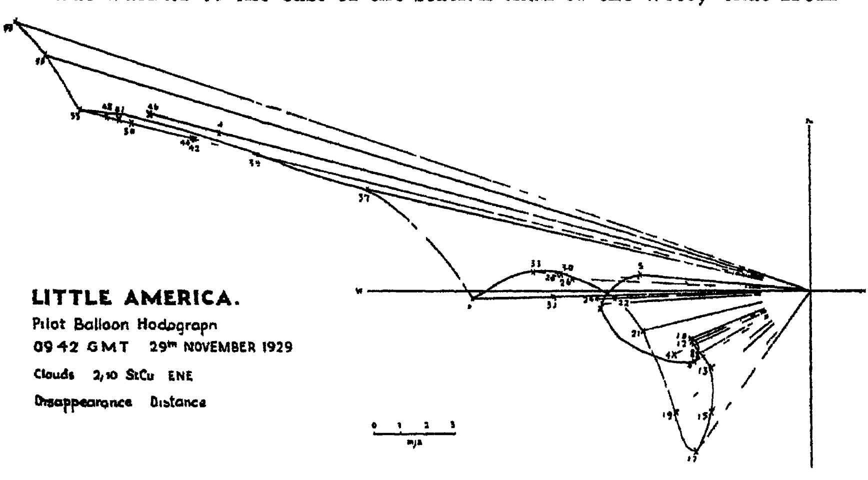


FIGURE 3.

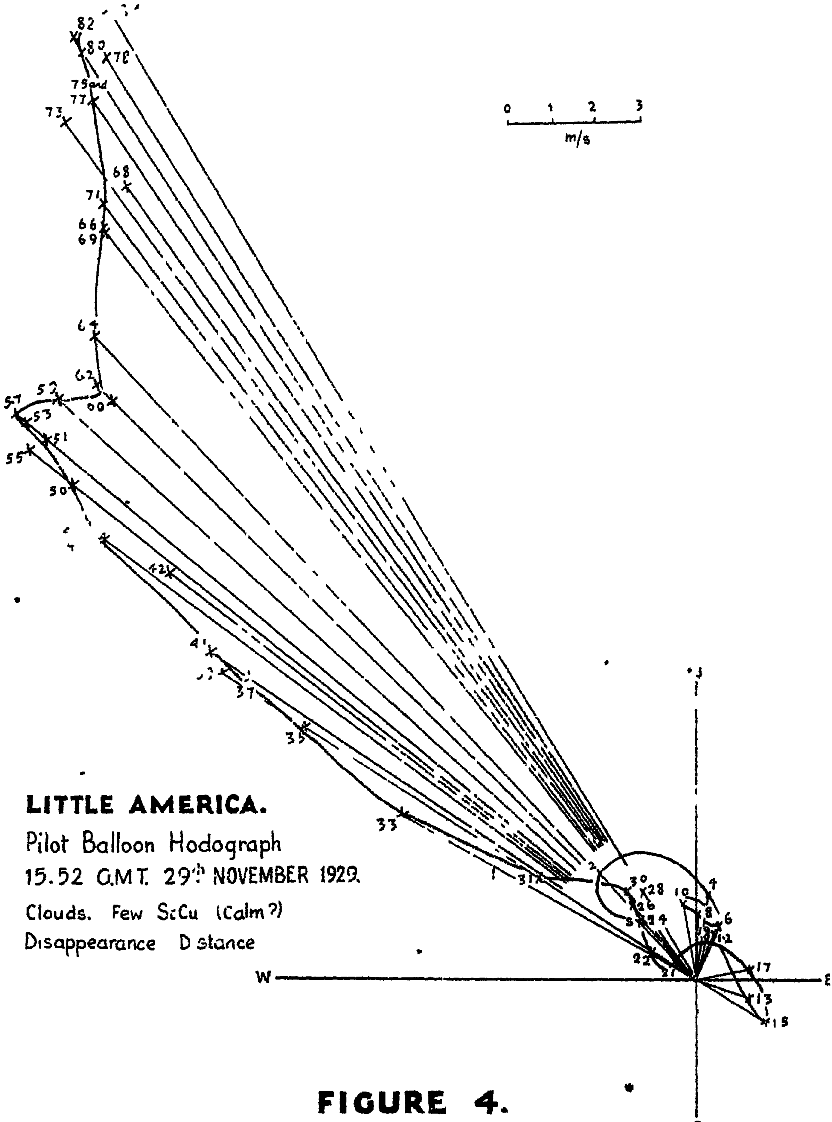


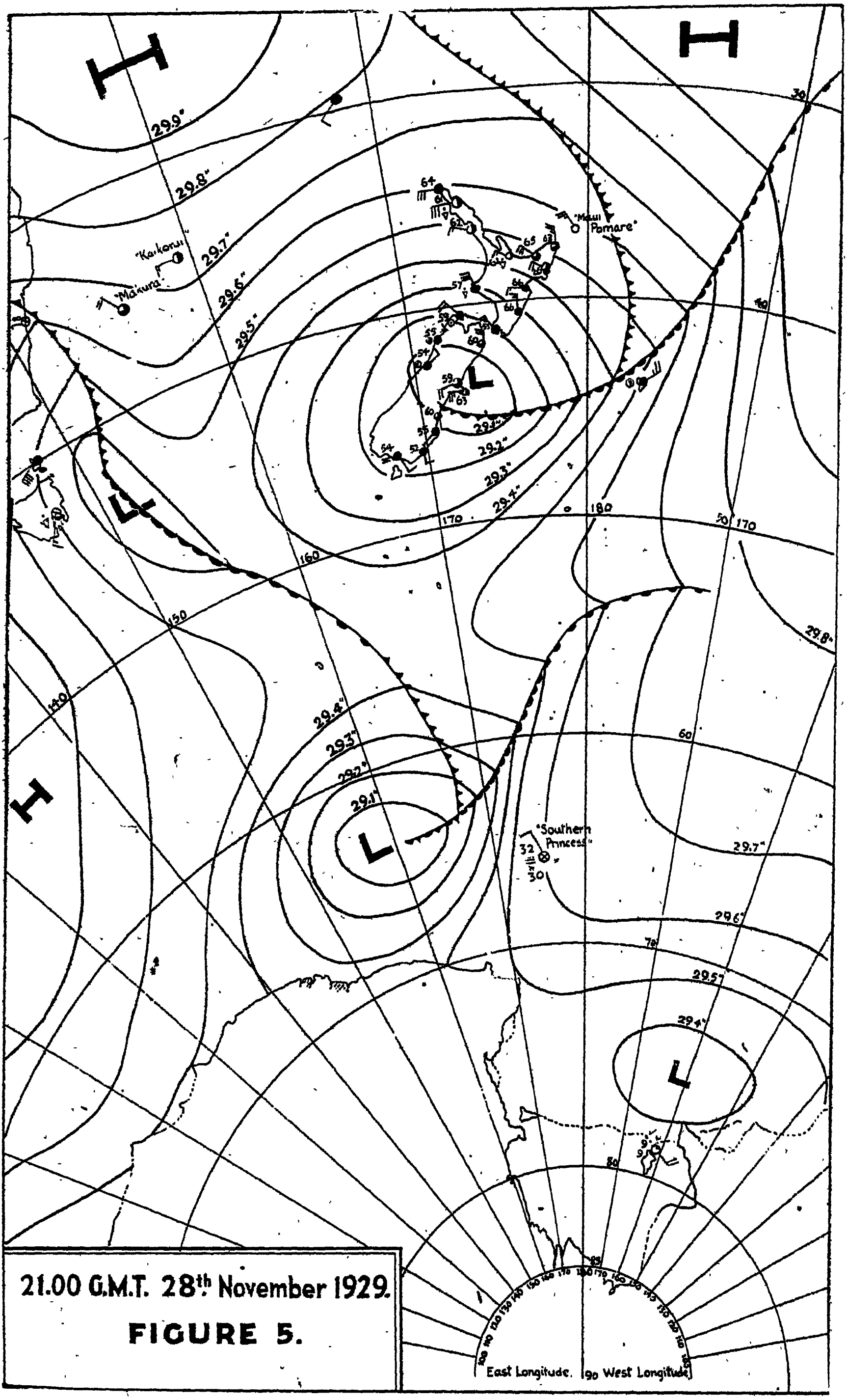
FIGURE 4.

1.7 km. to 5.3 km. the shear vector was directed approximately from south-east to north-west, indicating that the air in that layer was warmer to the south-west—in other words, that the gradient of mean temperature ran from south-west to north-east. It is also evident that up to 5.7 km. there is no sign of winds with a westerly component, such as would be expected if the theory of the polar vortex were always applicable to individual synoptic situations. If the upper winds are geostrophic, and there is every reason to

suppose that they were, a pressure gradient for south-easterly winds existed even at 5 km. and at that level isobars and mean isotherms were parallel.

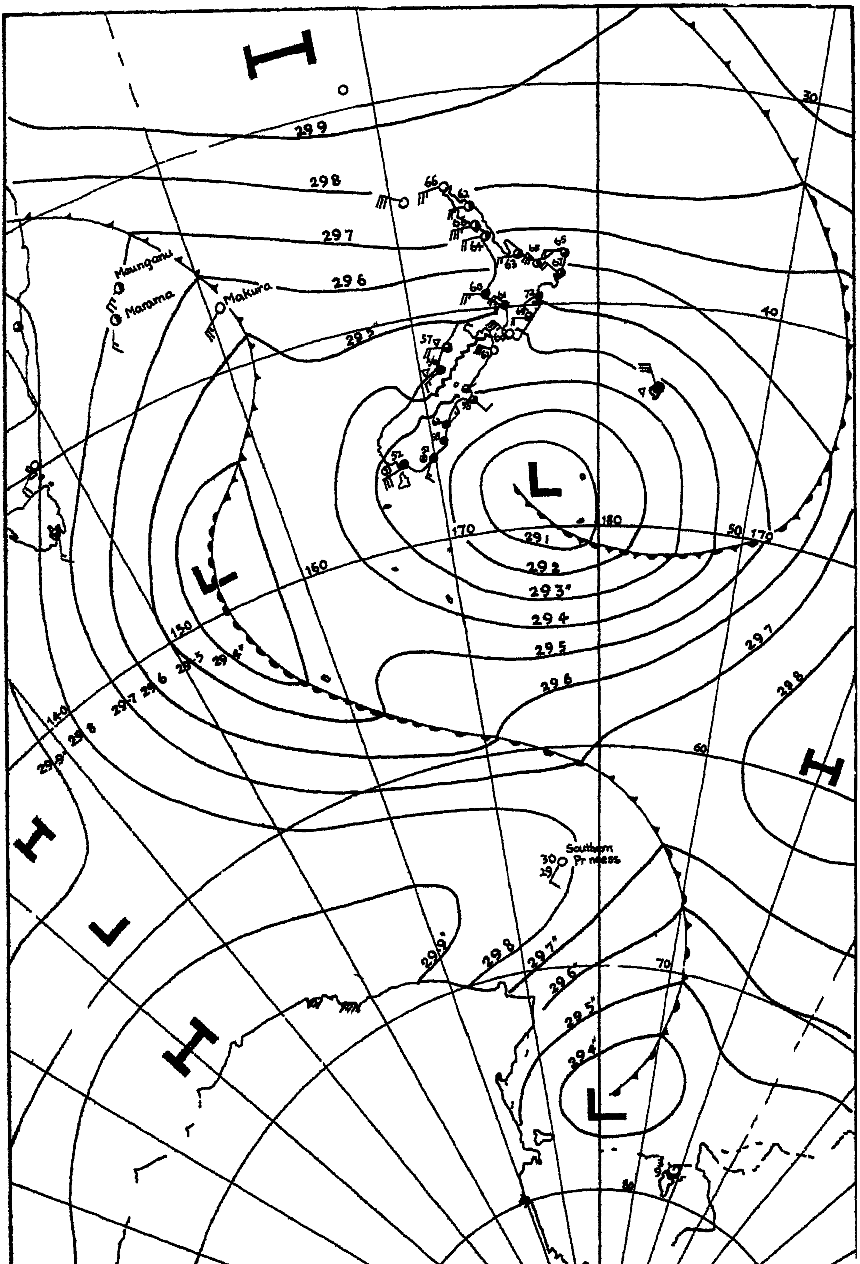
From the shear vectors below 5 km. it may be deduced that, while the air to the north-west, south-west and south-east of the station was relatively stable, a relatively unstable vertical stratification lay to the north-east. Some light may be thrown on this by the surface synoptic analysis. Reference to Figures 5 and 6 shows that at the time of the flight an old quasi-stationary low-pressure area covered the Ross Sea. In association with the southern portion of a meridional front, this low had moved into the Ross Sea on the 27th November (G.M.T.) after a period of nearly a week during which pressure had been abnormally high both at Little America and the "Southern Princess." The northern part of the meridional front (see 5 in bibliography) had meantime been stationary near Tasmania and had been deformed on the 28th, giving rise to the wave, which, partly occluded, is seen on Figure 5 approaching the "Southern Princess." The snow reported by the ship at 21.00 G.M.T. on the 28th is warm front precipitation. Captain Stuart has a note in his log for this day: "Very poor chasing weather. Incessant fog and snow." The log shows that the barometric minimum occurred at about 04.00 G.M.T. on the 29th, after which the barometer rose rapidly and the temperature (0° C. at the time of passage of the occlusion) fell to −4° C. at 16.00 G.M.T. on the 29th. The subsequent history of this depression and its amalgamation with the Ross Sea low may be inferred from Figures 6 and 7 and from the meteorogram for Little America shown in Figure 8. According to the meteorogram, the occlusion was very weak when it passed over Little America ("very light snow in the evening") and the depression had lost much of its previous intensity.

From this brief survey of the synoptic situation it will be seen that the surface geostrophic wind at 09.42 G.M.T. on the 29th was controlled by the pressure gradient on the southern side of an old quasi-stationary low in the Ross Sea. Apparently there was still a little activity in this low, since the distribution of the shear vectors in the lowest five kilometres indicates that a relatively unstable stratification existed in the air lying to the north-east of Little America. Nevertheless, the rise in pressure at the station shows that the low was filling up. Rossby and his pupils (4) have shown that it is possible from pilot balloon data alone to compute pressure changes due to advection in the lower atmosphere in extratropical regions. With an appropriate choice of units the three-hour tendency due to advection in the lowest 3km. is equal to the product of twice the area swept out by the horizontal wind vectors between the top of the friction layer and 3km., when the vectors are plotted in polar co-ordinates, and a multiplier that is constant for a given latitude. It is obvious from Figure 3 that advection in the lowest three kilometres would bring over the station relatively cold air from the north-east quadrant; it is easily computed by Rossby's method that the change in surface pressure induced by this advection would amount to $+0.014''$.



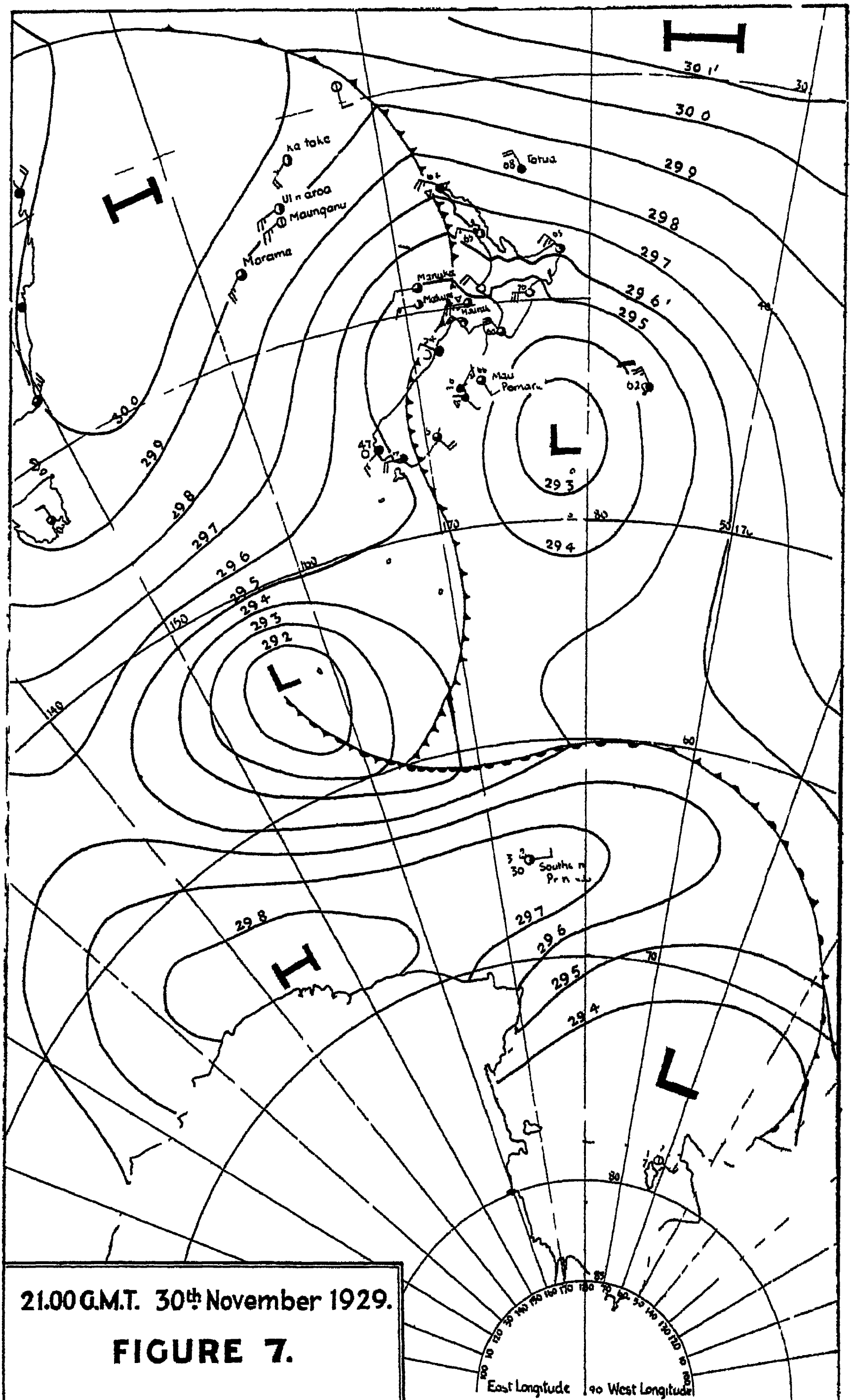
21.00 G.M.T. 28th November 1929.

FIGURE 5.



21.00 G.M.T. 29th November 1929.

FIGURE 6.



21.00 G.M.T. 30th November 1929.

FIGURE 7.

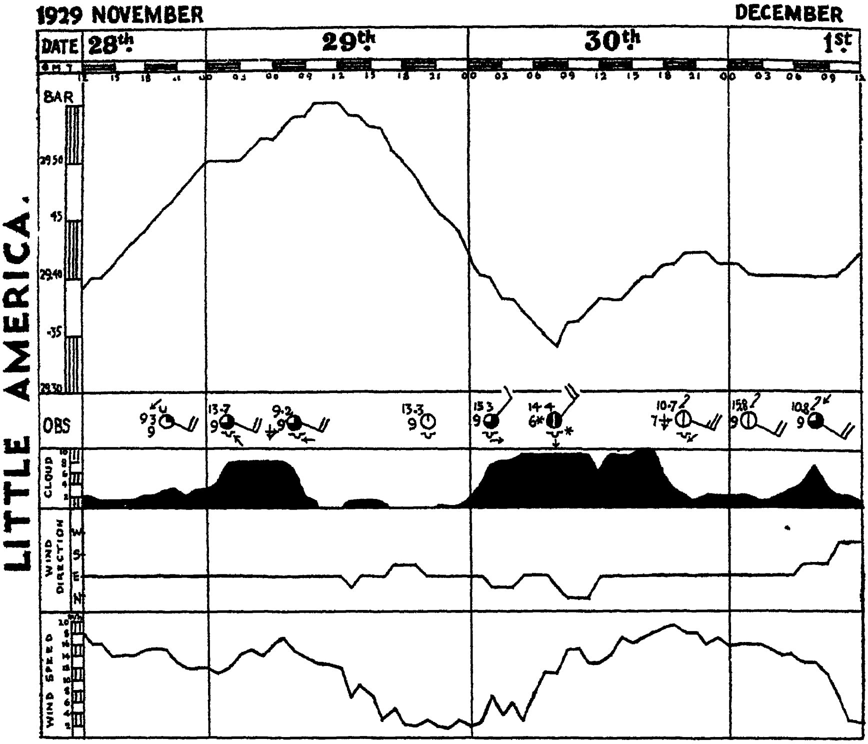


FIGURE 8.

The actual rise in pressure at Little America in the three hours preceding 10.00 G.M.T. as given in the tables of hourly values of pressure was +0.02″. It will be noticed that between 3 km. and 3.7 km. the shear increases rapidly; if, instead of calculating the pressure rise due to advection in the lowest 3 km., we compute that attributable to flow in the lowest 3.7 km. we find that the pressure rise would be +0.026″. The hodograph shows that no change in the mean temperature isotherms is to be expected from advection between 3.7 km. and 5.3 km. These facts justify the hypothesis that the three-hour pressure change was wholly due to advection of cold air in the lowest 3.7 km. and display excellently the power of Rossby's method.

The actual horizontal gradient of mean temperature for the lowest 3 km. in the neighbourhood of Little America is also calculable from the hodograph, and the calculation is facilitated by the fact that a temperature sounding to 3 km. was made about that time, on the South Polar Flight; from the observed temperatures the mean temperature has been estimated at −15° C., and this gives a horizontal mean temperature gradient of 5° C./735 km. from 205°. (South = 180°.)

At 15.52 G.M.T. 29th November, the time of the second long pilot balloon sounding, the hodograph of which is shown in Figure 4, the winds up to about 6 km. had decreased considerably in force

(on the average by about 9 m/s.) and had veered 20°–30°. The direction of the horizontal mean temperature gradient in the lowest 3 km. was still approximately the same (195°), but its magnitude had decreased to 5° C./2840 km. The hodograph shows that advection in the lowest 3.3 km. would have brought about a pressure fall; computation by Rossby's method gives — 0.006″ in three hours. The actual pressure fall at the surface in the three hours preceding 16.00 G.M.T. was — 0.01″. An interesting feature of the flight is the intrusion of a shallow layer of winds from a westerly quarter between 1 and 2 km. Evidently a relatively unstable atmospheric stratification still persisted somewhere north-east of the station. The westerlies appear to be associated with the approach of the depression from the north-west, as the meteorogram for Little America shows an accelerated pressure fall after 16.00 G.M.T., associated in its later stages with the movement of a bank of stratocumulus from the west and, during the period of snowfall, from the north. By 09.39 G.M.T. on the 30th, when the third balloon flight of this series was made, there was an almost complete overcast of stratocumulus, moving from the north. The flight was a short one as follows:—

09.39 G.M.T. 30th November, 1929. 0° = North. 270° = West.

Surface:	037°	5.8 m/s.
216 m:	033°	9.7 „
414 m:	018°	8.8 „
612 m:	006°	8.4 „
801 m:	357°	7.9 „
990 m:	357°	8.1 „
1,170 m:	358°	9.1 „
1,230 m:	354°	9.8 „

Cloud: 9/10 StCu. North.
Remarks: Few flakes of snow.
Disappearance: Entered StCu 1,230 m.

Wartime limitations of space prevent my giving a hodograph or table of the fourth flight, at 21.34 G.M.T. on the 30th, but the main features of the analysis are as follows:—The flight reached 3,150 m. and indicated that winds between east and north-east prevailed from the surface up to that level; speeds varied between 3.8 and 11.8 m./s., the mean speed being 6.4 m./s. The hodograph shows that the horizontal gradient of mean temperature in the layer explored by the flight was weak and had changed direction to 5° C./2370 km. from 130°. In the layer from the surface to 2 km. there were indications of an unstable stratification to the north of the station, while the layer above 2 km. still showed the effects of instability in the north-east. Advection in the lowest 3 km. should have produced a fall of pressure, but in fact the three-hour tendency at 22.00 G.M.T. was + 0.01″. We must therefore conclude that above 3 km. there was marked anticyclogenesis. It should be pointed out, however, that pressure began to fall at 22.00 G.M.T., but not, as may be seen from the meteorogram, with any rapidity.

For five days after the situation which is the topic of this paper winds from an easterly quarter prevailed in the upper atmosphere. Some of the soundings reached 10 km. and the lowest flight reached 3.8 km. In no flight during this period were there westerly components in the winds above 2 km., though some showed westerlies below that level.

Before passing to the explanation of the facts already elucidated, it may be as well to point out a few interesting features off the main track of inquiry:—

(a) There is a well developed friction layer when the wind in the lowest layer is greater than about 4 m./s. A modified Ekman spiral then appears in the hodograph. See Figure 3.

(b) When the surface and lower winds are light there is a katabatic flow from some southerly point. The winds veer with height, increase at first, then decrease, and finally show a very shallow layer of backing before settling down at about 1 km. to the geostrophic value. Figure 4 is a good example.

(c) Even in those flights with a well-developed friction layer, if the surface wind is off the Barrier, there will be distortion of the Ekman spiral, which I have taken to be due to a "katabatic" effect. The effect shows as a rapid increase in the wind at about 0.2 km. but without much backing, after which the wind backs rapidly without much increase in speed. (See Figure 3.) In the rare cases when the wind is off the Ross Sea this katabatic effect is not present.

(d) In long flights in the light season the tropopause can usually be located from the hodograph. The shear vectors show an abrupt change of direction as in Figures 3 and 4. At this time the tropopause seems to have been at about 5 km.

The upper wind regime and the surface changes in the meteorological elements during the 29th and 30th November, 1929, can best be explained in the following manner:—

(a) During the period, and for some time afterwards, an anticyclone of great vertical extent was located south of Little America. This anticyclone was warmer than its surroundings, up to great heights. The observations force one to the conclusion that it extended at least to the tropopause.

(b) The changes in the upper winds and horizontal mean temperature gradient on the 29th indicate that the anticyclone was becoming less intense and was probably re-oriented to extend off the continent somewhere in the north-west. This is partly confirmed by the high pressures at the "Southern Princess" on the 29th and 30th.

(c) To account for the position and structure of the anticyclone it must be assumed that it was maintained by inflow of air at high levels and that its warmth was due to subsidence in the whole air mass of which it was constituted. I would suggest that the source of the inflowing air at high levels was in the north-east, and lay not above the weak depressions over the Ross Sea but above the more vigorous and extensive disturbance over New Zealand.

(d) The depressions that moved into the Ross Sea appear to have little effect on the anticyclone. The second, which was quite active when it passed the "Southern Princess," was insignificant by the time it reached the Ross Sea. The front associated with it, likewise, rapidly lost intensity; it is doubtful, of course, whether any front, in the strict sense passed over Little America. However,

any remaining concentration of solenoids associated with the depression appears to have been effective only below 3 km. Evidently the dominating influence on the circulation was the polar anticyclone.

(e) October and November, 1929, were remarkable for the number of deep depressions that formed in the Tasman Sea—New Zealand area. This is now recognised in the Meteorological Office, Wellington, as a sign of low circulation index in the South-west Pacific. During periods of low index the eastward movement of the atmosphere and of the secondary circulations is much smaller, and the meridional flow, both at the surface and aloft, is more pronounced than usual. October and November, 1929, were also remarkable for the number of days when deep easterlies prevailed at Little America. This suggests that the inner portion of the polar vortex during periods of low index is not merely weak, as the M.I.T. School maintains, but is absent, being replaced by a warm, high anticyclone.

In conclusion, I wish to thank Flight Lieutenant Gabites and Pilot Officer Hutchings for reading and criticising the manuscript of this note and my wife for preparing the drawings for publication.

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Some Hitherto Unrecorded Plant Stations.

By A. J. Healy, Botany Division, Plant Research Bureau.

[*Read before Wellington Branch, September 23, 1942; received by the Editor, October 1, 1942; issued separately, March, 1943.*]

Section A.—Indigenous Species.

Angelica geniculata (Forst.f.) Hook.f.
* Wellington—coastal scrub, Ohiro Bay to Tongue Point, Wellington Harbour.
* Sounds—islands in Forsyth Bay, Pelorus Sounds; Motu Ngarara.
Eastern—in scrub on cliffs, Upper Hurunui Gorge; Waikari Valley near Greta; Mt. Brown, Upper Waipara River.

Asplenium anomodum Col.
Eastern—crevices in limestone bluffs, Limestone Creek, Waipara.

Blechnum patersoni Mett. var. *elongata* Hook. and Bak.
Sounds—creek banks, Mt. Stokes, Endeavour Inlet, Queen Charlotte Sounds.

Botrychium australe R. Br. var. *millefolium* Prantl.
Sounds—damp situations, Endeavour Inlet, Queen Charlotte Sounds.

Brachycome pinnata Hook.f.
Eastern—tussock grassland, Mt. Donald. c. 460m.

Celmisia graminifolia Hook.f.
Sounds—outskirts of beech forest, Kaituna Valley.

Cheilanthes tenuifolia Swartz.
North Eastern—hills between Fairhall Creek and Omaka River, Blenheim; Lowry Peaks Range near Waiau.
Eastern—modified tussock grassland, Omihi Valley; Motunau; Waikari Valley; Mt. Cass Range.

Chenopodium allanii Aellen (*C. triandrum* auth. non Forst.f.).
Wellington—in rocks and coastal scrub, Sinclair Head, Wellington Harbour.
North Eastern—Bourne Creek near Waiau; Stanton River; Lowry Peaks Range.
Eastern—this species has proved to be well distributed in North Canterbury; occurs on ranges on east and west of the Waikari Valley; ranges on north and south of the Upper Waipara River; hill country in coastal belt bounded on the east by the coast and west by the Omihi Valley, and to the north and south by the Waipara River and the Hurunui River respectively; Weka Pass; Governor's Bay, Banks Peninsula.

Clematis afoliata Buch.
Wellington—coastal scrub, Red Rock's Point; Karori Stream. In both these occurrences, male plants only were noted.

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* Botanical Districts as defined by Zotov (*N.Z. Journ. Sci. and Tech.*, vol. XIX, no. 8, 1938, pp. 483-485).

C. marata J. B. Armstr.
Eastern—in scrub, Mt. Brown, Upper Waipara River. Cheeseman (1925) says of this species—"South Island: Apparently common throughout." A close examination of a considerable area in North Canterbury revealed the plant in only this one locality.

Convolvulus erubescens Sims.
Wellington—coastal cliffs, Tongue Point, Wellington Heads.
Eastern—not uncommon in tussock grassland on the coastal belt between the Waipara and Hurunui Rivers; Hawarden; Weka Pass; Waikari Valley; Upper Waipara River.

Coprosma rhamnoides A. Cunn.
Eastern—beech forest, Mt. Noble. c. 600m.; manuka scrub, Teviotdale Station near Waipara. The specimens were referred to this species rather than to *C. polymorpha* Oliver due to the coriaceous texture of the leaves and the lack of polymorphy which is evident in the specimens which occur in Marlborough.

C. rugosa Cheesem.
Eastern—in scrub, Scargill, Waikari Valley.

C. virescens Petrie.
Eastern—in scrub, Scargill.

Dichelachne sciurea (R. Br.) Hook.f.
Sounds—not uncommon on range between Kaituna Valley and Waikakaho Valley. c. 450m.

Doodia media R. Br.
Wellington—forest remnant, Makino.

Dracophyllum urvilleanum A. Rich.
Sounds—scrub, Mt. Stokes. c.1,160m.; beech forest, Okaramio.

Dryopteris velutina (A. Cunn.) O. Kunze.
Sounds—coastal forest, Anokoha, Pelorus Sounds.

Edwardsia prostrata (Buch.) W. R. B. Oliver.
Eastern—common in exposed situations on hill country throughout North Canterbury. Considerable variation in the habit of this species was noted in the different localities where it occurred, and three marked forms were apparent—(a) a dense divaricate shrub forming mounds up to 0.5m. tall or prostrate sheets up to 1m. in diameter; (b) a divaricating shrub, mound forming at the base, from which a distinct trunk arises bearing a mass of divaricating branches at the extremity, the whole being 1.5 - 3.0m. tall; (c) on river flats in the area, a tall, divaricate shrubby form up to 3.5m. was not uncommon.

Epilobium microphyllum A. Rich.
Wellington—coastal cliffs, Sinclair Head, Wellington Harbour.

Eryngium vesciculosum Lab.
Eastern—swampy situation, Mt. Donald, c. 450m. This station is about 19 kilometres from the coast.

Festuca multinodis Petrie and Hack.
Sounds—coastal cliffs, Guard Pass, Forsyth Island.
Eastern—rocks near Mt. Oldham, Omihi Valley; calcareous sandstone cliffs, Waipara.

Fuchsia perscandens Cockayne et Allan.
Wellington—a small prostrate form of the species occurs on coastal cliffs and in windswept scrub, Sinclair Head, Wellington Harbour.
Eastern—not uncommon in scrub and amongst rocks, Happy Valley Station; Stoneyhurst Station; Pendle Hill; Blythe River; Waikari Valley; Weka Pass; Mt. Brown, Upper Waipara River.

Gahnia procera Forst.
Sounds—open hillsides, Kaituna Valley.

Geniostoma ligustrifolium A. Cunn.
Sounds—coastal forest, Saratoga, Pelorus Sounds.

Gentiana astoni Petrie.
Eastern—windswept north-west slopes, Mt. Donald, c. 490m.; in rocks along escarpment, North Deans Range, Waipara River, 500m. The occurrence of this species in the above habitats removes it from the list of local endemic species of the North Eastern District, and extends its range southwards by some 160 kilometres. At the time of discovery (June, 1941) plants were flowering profusely.

Gymnogramme leptophylla (Swartz) Desv.
Wellington—moist, shady bank, Seatoun.

Halorrhagis colensoi Skottsberg.
North Eastern—cliffs above Jed River near Gore Bay, Cheviot.

Hebe cheesemanii (Buch.) Cockayne et Allan.
Eastern—rock crevices, Mt. Noble, c. 1,060m.

H. raoulii (Hook.f.) Cockayne et Allan var. *maccaskillii* Allan.
Eastern—on rock faces, Mt. Noble, c. 600m.; in crevices of escarpment and amongst scrub, Mt. Brown; North Deans Range, Upper Waipara River.

Helichrysum selago (Hook.f.) Benth. var. *acuta* Cheesem.
Eastern—rock outcrops, Hayden Downs Station, Waitohi River.

Juncus maritimus Lam. var. *australiensis* Buchen.
Eastern—the forms present on the coast between the mouth of the Waipara River and the Amberley Beach locality differ from the normal forms in that the inflorescences are much compacted.

Lindsaya cuneata (Forst.f.) C. Christ.
Sounds—coastal forest and scrub, descending to sea-level, Te Puru, Pelorus Sounds.

L. linearis Swartz.
Wellington—common in manuka scrub, Eastbourne, Wellington Harbour.
Sounds—in manuka scrub, Te Puru; Pohuenui; Forsyth Island, Pelorus Sounds; Waitaria Bay; Taradale, Kenepuru Sounds; near Okaramio, Kaituna Valley.

Melicope ternata Forst.
Sounds—coastal forest, Te Puru; Saratoga; Okoha, Pelorus Sounds; Forsyth Island; Motu Ngarara.

Metrosideros scandens (Forst.) Druce.
Sounds—coastal forest, Te Puru; Anokoha; Beatrix Bay, Pelorus Sounds.

Microlaena polynoda Hook.f.

Wellington—forest remnants, Porewa; Arapata, Rangitikei River.

Sounds—coastal forest, D'Urville Island, J. H. McMahon; Motu Ngarara.

Muehlenbeckia astoni Petrie.

North Eastern—terraces near Chandler's Lagoon.

Eastern—terraces of Waiau River, between Rotherham and Waiau; Hurunui River west of Ethelton; near Scargill, Waikari Valley; terraces of Weka Creek from confluence with Waipara River to mouth of the Weka Pass; Waipara River from near foot of Mt. Brown to mouth of the river, with a concentration of plants in the vicinity of Waipara township. The distribution of the species in the South Island has been recorded by Miss Jenkins (1931) and W. Martin (1938), but there is no previous record of its occurrence in the Eastern District. It was found to be well dispersed in North Canterbury, and in the vicinity of Waipara township it occurs in greater quantity than in the type locality; the cited localities are all inland, at altitudes from 70-240 metres. The occurrence of the species at Waipara extends the range about 160 kilometres south of the previously recorded stations.

Myosurus novae-zelandiae W. R. B. Oliver.

Eastern—moist shingle, Waipara River.

Myrtus bullata Sol. ex A. Cunn.

Sounds—coastal forest, Te Puru; Beatrix Bay; Manaroa; Hopai, Pelorus Sounds; Kenepuru Heads; Waitaria Bay; Taradale; Portage; Nopera Bay, Kenepuru Sounds.

Nothochlaena distans R. Br.

Sounds—coastal cliffs, Picton, J. H. McMahon !

North Eastern—hills between Fairhall Creek and Omaka River, Blenheim; rocky situations, Lowry Peaks Range, near Waiau; hills between Mason River and Stanton River, Waiau.

Olearia cymbifolia (Hook.f.) Cheesem.

Eastern—in scrub, Mt. Noble, Upper Hurunui River.

Orthoceras strictum R.Br.

Sounds—not uncommon in scrub, Pelorus and Kenepuru Sounds; Kaituna Valley.

Ourisia caespitosa Hook.f.

Eastern—windswept north-west face, Mt. Noble, c. 1,000m.

Pachystegia insignis (Hook.f.) Cheesem.

North Eastern—rock outcrops, Lowry Peaks Range, Waiau; terraces of Leader River.

Paratrophis opaca (Banks and Sol.) Britton and Rendle.

Sounds—windswept islands, Forsyth Bay, Pelorus Sounds—here it assumes a prostrate growth habit; coastal forest, Motu Ngarara.

Peperomia urvilleana A. Rich.

Sounds—common on islands and larger reefs, Forsyth Bay, Pelorus Sounds.

Plantago lanigera Hook.f.
Eastern—swamp, Mt. Donald, c. 460m.

Polypodium dictyopteris Metten.
Sounds—damp banks in coastal forest, Te Puru; Anokoha, Pelorus Sounds.

Prasophyllum rufum R. Br.
Sounds—in manuka scrub, Portage; Te Mahia, Kenepuru Sounds.

Pterostylis trullifolia Hook.f.
Sounds—not uncommon in scrub, Pelorus Sounds; Forsyth Island; Taradale; Kenepuru Heads; Waitaria Bay; Portage, Kenepuru Sounds.

Pseudopanax ferox T. Kirk.
Sounds—common in coastal forest, Motu Ngarara.

Taraxacum magellanicum Comm.
Eastern—tussock grassland, Omihi Valley.

Tetragonia trigyna Banks and Sol. ex Hook.f.
Eastern—on escarpment, North Deans Peak, Upper Waipara River, c. 370m.

Trichomanes strictum Menz. ex Hook. and Grev.
Sounds—beech forest, Mt. Stokes, c. 760m.

Trisetum saxeticolum Cockayne et Allan.
Sounds—common on coastal cliffs and rocks, Outer Pelorus Sounds and outlying islands.

Section B.—Introduced Species.

Acacia armata R. Br. Kangaroo thorn.
Spreading from hedges near Sanson.

Albizzia lophantha Benth. Brush-wattle.
Well established on hills near Seatoun, Wellington.

Amaranthus albus Linn. White amaranth.
Established in old metal quarry and adjacent waste land, Terrace End, Palmerston North.

Bromus carinatus Hook. et Arn.
Established in waste places and on roadsides in North Canterbury—Rangiora; Waipara; Waikari; Tormore; Amberley; Scargill; Ethelton; waste places—Picton; Blenheim; Seddon.

B. tectorum Linn.
Abundant on terraces of rivers and creeks, Waipara Flats; Weka Pass; Lower Omihi Valley; well established in low tussock grassland in area between Limestone Creek and Mt. Cass, Waipara.

Cakile edentula (Bigel.) Hook.
Coastal sands near mouth of Waipara River, Canterbury.

Calotis lappulacea Benth.
Well established on eroded terrace banks, Lower Waipara River, near Amberley. Some four to five years ago the occupier of the property where the plant occurs eradicated all the plants at that time, but in the intervening period the weed has spread rapidly, and in parts forms a pure association.

Carduus crispus Linn.

Has appeared recently on a ballast heap, Wellington Harbour; a patch noted in low tussock grassland, Davaar Station, Motunau.

Centaurea melitensis Linn.

Occurs on roadsides and waste places, Waipara; Weka Creek; lower Omihi Valley; Blind River near Seddon.

Chamaepeuce afra (Jacq.) D.C.

Not uncommon in shingle and on lower terraces of Waipara River; Weka Creek; Omihi Creek; thoroughly established, forming large patches in rocky areas in tussock grassland, Mt. Cass; hills between Mt. Brown, Upper Waipara River and Weka Pass; noted in permanent pasture, Waikari Valley. This species is on the increase in the loose, sandy soil along the rivers in the vicinity of Waipara.

Clematis vitalba Linn.

An escape from cultivation; established in waste places, Urenui; Feilding, Palmerston North; Shannon; Wellington City and suburbs; Kaikoura; Waiau; Waikari; Amberley.

Cynodon dactylon (Linn.) Pers.

Sandy situation, Kowhai River near Leithfield; waste land, Christchurch.

Diplotaxis tenuifolia (Linn.) D.C.

Well established on ballast heap, Wellington.

Duchesnea indica (Andrew) Focke.

Damp situation, Botanical Gardens, Wellington.

Erophila vulgaris D. C. (*Draba verna* Linn., in part.)

Waste land, Culverden, North Canterbury.

Falcatula ornithopodiodes (D.C.) Wilmott.

Not uncommon in coastal areas, Wellington Harbour; in waste places and pastures, Blind River, Seddon.

Hieracium pilosella Linn.

Thoroughly established on banks of railway cuttings between Hurunui River and Greta, Waikari Valley; the species is spreading into low tussock grassland on the western slopes of the Waikari Valley in the vicinity of Greta.

Hypericum acutum Moench.

Swampy situation, Akatarawa Valley.

Koeleria phleoides (Vill.) Pers.

Waste land, Wellington Harbour.

Lactuca serriola Linn.

Waste land, Blenheim, Seddon; Kaikoura; Waiau; Culverden; Waikari; on roadside, Weka Pass.

Lagenophora gunnii (Hook.f.) Black.

Coastal pastures, Titahi Bay; damp situations in tussock grassland, Omihi Valley; well established in larger gulleys on Meadowbank, Wrekin Hills and Brookby Stations, Marlborough; on the Wrekin Hills Station the plant occurs in patches of an acre and greater on the flats in the gulleys.

Lamium amplexicaule Linn.
Abundant in gardens and waste places in Rangiora; waste land. Waipara, common in cultivated land about homesteads, Hayden Downs and Mt. Virginia Stations, North Canterbury; waste land, Blenheim, Seddon and Dashwood.

Lavatera cretica Linn.
Waste places, Paekakariki, R. Mason! Shannon; Wellington.

L. plebeja Linn.
Established in waste land, Palmerston North.

Linaria arvensis (Linn.) Desf.
Occurs sparingly in low tussock grassland, Wrekin Hills; Brancott Station, Fairhall, Blenheim; common in ballast in Railway Yards, Seddon; Dashwood; occurs along railway line between Dashwood Pass and Seddon.

Linum gallicum Linn.
Coastal cliffs, Picton; occurs sparingly in area between Te Mahia and Portage, Kenepuru Sounds.

Lychnis coronaria (Linn.) Desv.
Established in old bush burn, Beatrix Bay, Pelorus Sounds; common along bed and terraces, Fairhall Creek, near Blenheim; dry banks, Leithfield; Hurunui River near Ethelton; thoroughly established on cliffs of the Upper Waipara River near Mt. Brown, and spreading up numerous gulleys to the stony terrace land.

Medicago minima (Linn.) Desr.
Common on the terraces and bed of a number of rivers in North Canterbury—Waipara River, Weka Creek; Omihi Creek; Kowhai River; Mason River; Stanton River; in the vicinity of Waipara the species is common in tussock grassland, particularly on dry north-west faces.

Melianthus major Linn.
Established in waste places, Gore Bay, Cheviot; Leithfield; Amberley.

Melissa officinalis Linn.
Occurs along banks of Makino Stream, Feilding; common in sheep yards, Te Puru; Forsyth Island, Pelorus Sounds; roadsides and waste land, Omihi Valley, North Canterbury.

Mycelis muralis (Linn.) Rchb.
Bush margins and in scrub, Stanton River, Waiau.

Nassella trichotoma (Nees) Hack.
Occurs in area between Taylor River and Omaka River, Marlborough; widespread throughout North Canterbury—Kowhai River; Waipara River from near Mt. Brown to the coast; Weka Pass; Waikari Valley; Motunau; Hurunui River from confluence with Waikari Stream to within a short distance from coast; Cheviot; Hawarden; Parnassus; Waiau. This species has spread rapidly in recent years, and over some 10,000 acres has formed practically a pure association.

Papaver argemone Linn.
Appeared recently on a ballast heap, Wellington Harbour; occurs sparingly in cereal crops about Waipara and the Omihi Valley.

Pelargonium radula L'Herit.
Well established on hillsides above Seatoun, Wellington.

Pennisetum macrourum Trin.
A garden escape, spreading in pasture on river flats, Omihi Valley.

Pholiurus incurvus (Linn.) Schinz et Shell.
Coastal sands at mouth of Waipara River, North Canterbury.

Plantago varia R. Br.
Occurs in tussock grassland, Stoneyhurst Station, North Canterbury.

Polygonum mite Schrank.
Common along Waiwhetu Stream, Hutt Valley.

Ranunculus muricatus Linn.
Waste land, Taita Gorge, Hutt Valley.

Rubus phoenicolasius Maxim.
Established and spreading, bush outskirts near Shannon.

Salvia verbenaca Linn.
Occurs in pasture, Dannevirke; Paekakariki; Kaikoura; well established on roadsides, Hawarden; Waipara; Waikari: Mt. Virginia Station, Waitohi River, North Canterbury; in tussock grassland, Mt. Noble, Upper Hurunui River—introduced to this locality in horse feed when contractors were putting the road through to Lake Sumner.

Satureja vulgaris (Linn.) Fritsch.
Common in an old bush burn, Laverique Clearing, Beatrix Bay, Pelorus Sounds.

Scleropoa rigida (Linn.) Griseb.
Thoroughly established along the lower Weka Creek and Waipara River near confluence of the Weka Creek.

Sedum acre Linn.
Common on dry faces in tussock grassland up to 300 metres, North Canterbury.

Senecio mikanioides Otto.
Established in waste land, Kaikoura: Cheviot: Amberley; Leithfield.

Silene conica Linn.
Dry roadsides and pastures in vicinity of Waipara River.

Solanum marginatum Linn.
Occurs as a garden escape in several localities about Wellington City; thoroughly established and spreading in country between Beatrix Bay homestead and Manaroa, Pelorus Sounds; occurs in plantations and about sheep yards, Motunau Station, North Canterbury.

Stuartina muelleri Sond.
Not uncommon on the hills to the south of the Wairau River, Marlborough—occurs on the hills in tussock grassland between the Taylor River and the Omaka River; in tussock grassland between the Weld Pass and the coast.

Tillaea decumbens Willd.
Established in Railway Yards, Paekakariki; dry roadside, Taita Gorge, Hutt Valley.

Trifolium angustifolium Linn.
Occurs in waste land, Wellington City.

T. resupinatum Linn.
Dry situations, Kenepuru Heads, Marlborough Sounds; common in pastures on country between Seddon and Lake Grassmere, Marlborough; river terraces near Waipara; waste land, Wellington.

T. suffocatum Linn.
Established on roadsides, Eastbourne; Seatoun, Wellington; common in pastures, Sinclair Head, Wellington Harbour.

Tunica prolifer (Linn.) Scop.
Occurs in dry situations, Waipawa River, Hawke's Bay; widespread along rivers in North Canterbury—Waipara River; Weka Creek; Kowhai River; Hurunui River; Waiau River; Stanton River; Mason River. At Waipara this plant is abundant in low tussock grassland to the north of the Waipara River.

Urtica dioica Linn.
Noted on roadside near mouth of the Waiwhetu Stream, Hutt Valley; occurs in small quantity in Botanical Gardens, Wellington.

Veronica anagallis Linn.
Established in swamps, Kekerangu; common along the Waipara River near the Waipara township; Weka Creek; Omihi Valley. About Waipara the species is common in ponds, swamps, etc., extending its range some distance from rivers and creeks.

V. scutellata Linn.
Common in streams and swamps, Stanway near Feilding. The species still persists in the original locality along the Makino Stream, Feilding.

V. verna Linn.
Abundant on the terraces of the Weka Creek and Waipara River, extending over a large part of the Waipara Flats; occurs sparingly on light soils, Culverden.

NOTE.—Specimens of the species listed in this paper are deposited in the Herbarium of the Botany Division, Plant Research Bureau, Wellington.

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Observations on the Growth of *Macrocystis* in New Zealand.

With a description of a free-living form.

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INTRODUCTION.

SKOTTSBERG (1907) figured diagrammatically the branching system of *Macrocystis pyrifera* (L.) Ag. Illustrations and descriptions published by Brandt (1923), Setchell and Gardner (1925), and Setchell (1932) all fit into Skottsberg's scheme, which they supplement by indicating which of the leaf blades have basal cysts or bladders. Setchell's photographs and very clear sketches (1932, Pl. 33, 34, 35) show that *M. integrifolia* Bory, though differing in the haptera and the flattened "rhizomes," has the same general plan of branch and leaf arrangement.

In New Zealand *M. integrifolia* has not so far been observed, and *M. pyrifera* conforms so rigidly to the normal scheme of branching (Moore, 1941; Rapson, Moore and Elliott, 1942) that any departure seems noteworthy.

Brandt (*loc. cit.*, p. 18) describes the life cycle of an individual long branch. "As the frond approaches the surface the rate of growth decreases, the terminal leaf gradually becomes smaller and less delicate, and fewer laterals split off, until finally no more are formed. . . . After division ceases the laterals (i.e., leaves) continue to grow in length and breadth. . . . The terminal leaf seldom attains the size of the laterals." The sequence of changes at the end of the frond as it ages are not described further, but Figure 15 shows the kind of "young leaves at the tip of a nearly mature frond."

This paper records how the growth of a long frond can be arrested, terminated, or modified in various ways.

ARREST OF GROWTH.

(A) Breakdown of tissues in the most actively growing part of the terminal leaf.

This type of arrest was noted as common at D'Urville Island in January, 1941, at Port Adventure in February of the same year, and a month later, by Mr. Rapson, in several other beds at Stewart

Island. At Thorndon, Wellington, in the following October, out of 27 tips collected near the water surface in one area 11 showed breakdown of this kind. In another sample, comprising seven whole plants, the total number of tips was 52, of which probably more than half had not yet reached the surface. Of the 15 tips showing breakdown only three were on fronds less than 1.2 metres long, while of the 19 fronds over 1.2 metres long only one was actively growing. Near low tide mark this type of injury has been seen on young plants only a few decimetres long.

Breakdown seems to be caused by some agency acting near the surface and over a considerable area at once. Physical stresses, chemical changes (e.g., excess of fresh water or pollution by sewage) or pathological organisms might be responsible. Black rot, a bacterial disease recorded by Brandt, does not seem to be involved. The stipe and any partly swollen bladders attached to it may continue to grow for some time and persist after the leaf blades have fallen. Breakdown of this kind is to be regarded as an accident cutting across the normal development of the frond.

(B) Derangement or modification of the growing tissues.

(1) *Incomplete Fission.* The slit in the growing region of the terminal leaf is occasionally incomplete so that two bladders remain attached distally, though proximally they are distinct, and their two blades develop independently of one another. This kind of monstrosity has been seen on fronds that display no other abnormality. It does not involve any arrest of growth and is mentioned here only for completeness.

(2) *Senescence.* During the maturation of a leaf on a long frond, the stem connecting blade to stipe swells to form a gas-containing bladder that helps to buoy up the frond. When a swelling of this kind begins to develop in the growing region of the stipe within the terminal blade (*Sprossspitze* or *Endfähnchen* of Skottsberg) further growth is limited to the expansion and maturation of the organs already laid down. If the swelling is very near the end the result shows nothing but normal leaves, with one terminal (c.f. Brandt, *loc. cit* Fig. 15). If, as frequently happens, the swelling of the immature stipe extends along below the bases of several developing leaves, there are various modifications of normal leaf and stem that may emerge. (Fig. 1, Plate 34.)

Where bladders in stipes occur at all they are usually fairly abundant—e.g., out of 86 tips that could be raked from one rock 41 had bladders of this kind. Amongst these, 12 were at an early stage of development, 10 of medium size, and 19 fully grown or wearing away. Early and late stages can be found on different fronds of a single plant. No correlation between length of frond and size of bladder in stipe was established, but amongst 46 fronds measured the distal leafy portion averaged in 14 with small stipe bladders 1.3 metres, in 13 with medium-sized bladders 1.0 metres, and in 19 with large stipe bladders 0.6 metres.

Immediate environment seems to be more effective than season. At Worser Bay, in two places 45 metres apart, all accessible tips were taken on two occasions. The ratio of total number of tips to those with stipe bladders was, in September, for the outer place 65:6, for the inner place 74:12. Corresponding figures for the same places in the following February were 49:1 and 86:41. In a third locality some six kilometres away, from a patch cleared in October, 19 surface tips taken a year later included 6 with bladders in stipes. This kind of tip has also been collected in Wellington in July, and in March, 1941, Mr Rapson found that at Ruapuke Island, Foveaux Strait, 14 out of 38 tips collected were of this kind. Here, and at Ocean Beach, Stewart Island, where he reported this same sort of "moribund tip," the kelp is growing in quite deep water in off-shore beds.

Brandt (*loc. cit.*, p. 19) says: "When the water is too warm for vigorous growth, some leaves next the tip do not develop."

The temperature affecting the growth of the frond tip is that within a few decimetres of the surface at any given time, not the average or mean temperature. Surface temperatures, taken at weekly intervals at 9 a.m. over a year at Worser Bay, very near to *Macrocystis* beds, are recorded by Oliver (1923). They range from 9.1° C. to 17° C. A surface temperature of 20° C. at Island Bay is said to be exceptionally high. Greater temperatures are recorded in the *Macrocystis* beds of the North American west coast, where Brandt associates high temperatures with poor yields. His Figure 12 shows that at 13.45° C. the number of hundreds of tons of wet kelp per square mile of area harvested was 21, at 16.75° C. 17, and at 20.65° C. only 8.

The development of a bladder within the stipe may be a normal occurrence in the maturation of every healthy frond that has attained the limit of growth permitted by its particular environment. The number present in any bed would then depend on its past history (e.g., time of cutting or removal of fronds by storm, etc.) and on the age and rate of growth of the fronds. They are found on short, young stems in plants attached near low tide mark, and therefore are probably in some way correlated with surface conditions, of which temperature may be important. Whereas an actively growing tip droops well under water, with the development of a stipe bladder it is raised up to the surface, where it is exposed to more severe conditions.

Whatever the stimulus that causes these stipe bladders to form, they restrict further elongation of the fronds affected, and when present in large numbers indicate that the bed concerned is in the process of temporary deterioration.

REJUVENATION.

Brandt, in describing the development of a long frond, states that the stem of about the third lateral (leaf) from the base rounds out and becomes a hollow cyst or float, and all subsequent laterals develop cysts.

Figure 1 shows that, in conjunction with the swelling of the terminal part of the stipe, leaf blades lacking their own basal bladders may be produced. Several cases can be recorded where bladderless leaves occur near the tip of a long frond beyond the usual bladdered leaves without any concomitant swelling of the stipe. This phenomenon, which may be called rejuvenation, may follow when the *Endfähnchen*, after a relatively inactive period, begins to divide again, and, like the basal leaves, forms at the first few divisions bladderless blades.

Types of Branching of Long Frond.

Amongst the leaves at the base of a plant it seems to be a fairly general rule that any blade not provided with a bladder is capable, sooner or later, of dividing unequally to give one or more bladderless leaves like itself, together with the initial of a new long frond. The formation of bladderless leaves near the tip of a frond introduces the possibility of the production of a second order long frond, branching off from the normally unbranched long frond, which Setchell *(loc. cit.)* designates as of the final order.

Specimen X, Figure 2, if the second interpretation is correct, is an example of this sort of thing, as it might develop on a frond whose growth was already limited by the production of a stipe bladder. Other specimens figured show earlier stages in the development of such a branch a little further removed from the frond tip.

Specimens secured from Paterson Inlet, Stewart Island, illustrate branching of long fronds very fully, both in early and late stages and in some variety of form (Figure 4, Plate 35). The type of branching already described, where a bladderless blade on a long frond divides heterosotomically (Setchell, 1932, p. 453), is well represented.

A second type of branching, of which an early stage is suggested by a specimen from Worser Bay, is even more common. In this case it is the blade of a bladdered leaf, apparently normally produced in the ordinary sequence, that divides heterosotomically to give rise to a branch long frond, with, in nearly every case, at least two bladderless proximal leaves. This contrasts with the statements of Skottsberg (1907, p. 91), Brandt (1923, p. 12) and Setchell (1932, p. 454) that there seems to be no evidence that a blade which has developed (or started to develop) a bladder ever proceeds to a longer-branch production.

A third type of branching differs from the second in that the initial heterosotomic division extends right down to the stipe, its products being one bladdered leaf, attached to the stipe at the point of origin of the new branch, and one bladderless stalked leaf, from which, by continued heterosotomic division of the ordinary kind, the new frond develops.

The figures show how these types of branching are associated on individual specimens, and that branches can be counted to the fourth order.

PROVENANCE OF BRANCHED SPECIMENS.

Although several Wellington specimens show aberrant leaves that apparently could give rise to branches on long fronds, actual branching of this kind has been seen only in specimens from Paterson Inlet, Stewart Island, grown under very special conditions.

Mr Roy Traill, of Leask's Bay, informed the present writer during the kelp survey of February, 1941, that, in addition to the beds of kelp growing on the outer coast, with conspicuous floating parts covering wide areas of the sea surface, there were, within Paterson Inlet, considerable areas of quiet bays where a similar kelp grew, completely submerged and close to the mud-sand bottom, from which it was often lifted in quantities on boats' anchors.

One of these areas near Kaipipi Point was visited in Mr Traill's launch, and a single specimen was secured in exactly the type of place previously described. There was not time to explore further, but a month later, in another but quite similar place, Ryan's Creek, suggested by Mr Traill, Mr Rapson collected more specimens, that, like the first, possess a number of features that distinguish them from open-water *Macrocystis*.

CHARACTERISTICS OF SUBMERGED MACROCYSTIS.

Branching.—All specimens show branching of the long fronds of the types described above and illustrated in Figures 3 and 4.

Texture.—All leaf blades, though not abnormally small for inshore plants, are of very delicate texture, completely flaccid when out of water, and entirely lacking that coriaceousness that enables a leaf on a floating stipe to flick out of the water and wave like a flag in high wind. (Leaves from a two-metre-long attached juvenile hauled up from 9 metres depth at Maori Kelp, Stewart Island, were similarly delicate.) When lifted into a boat with anchor or fishing line the long, clinging weed has an investing layer of slimy mud, possibly partly bacterial, which makes it particularly objectionable to handle.

Bladders.—Bladders are narrow and not fully distended as they are in floating fronds. Stipes are slender and internodes short.

Reproduction.—No fertile leaves were seen. Fronds are no doubt divided by the decay of older parts of stipes.

Growing tips.—*Endfähnchen,* though unusually delicate, are healthy and actively dividing.

Attachment.—Holdfasts are completely absent from all specimens examined. The oldest part of each is a ragged length of stipe, more or less decayed at its lower end.

HABITAT OF SUBMERGED MACROCYSTIS.

Paterson Inlet is a wide arm of the sea, open to the east and running approximately westwards across Stewart Island. Tides and winds cause considerable, sometimes violent, water movements in the

central and deeper stretches of the Inlet, and here floating fronds of attached *Macrocystis* fringe projecting points. There are many sheltered, almost land-locked bays seldom disturbed by currents or waves where muddy bottom deposits can accumulate. It is in such places, in comparatively shallow water (2 metres) that the submerged *Macrocystis* was collected, and that extensive beds of it are said to occur. The tide range in the Inlet, calculated from data given in the Nautical Almanac, is from 1.6m. at neap tides to 3m. at spring tides.

" Loose-lying Formations " of Algae.

These beds of submerged *Macrocystis* would appear to be equivalent to the " loose-lying formations " of the Baltic (Rosenvinge, 1898, Svedelius, 1901) which are analogous to the " Migrations-formation " described by Schiller (1909) from the Adriatic Sea. An account of the former (Baker and Bohling, 1916, p. 339) is quoted for comparison.

" All the loose-lying formations occur within the sublittoral region. They are composed of different forms derived from the attached species of the littoral region, which, when torn loose by the waves and carried by the currents into still places, collect together in great masses on the floor of the sea. Here they continue to grow, reproducing themselves by vegetative means, often over a mobile bottom, otherwise destitute of vegetation; but they never become embedded or fixed to the substratum. The dwarf *Fuci* are dominant forms in the uppermost of the two chief loose-lying formations of the Baltic; the formation characteristic of deeper waters is dominated by *Phyllophora brodiaei* f. *elongata*. The loose-lying *Fucus* formation occurs, in general, at a little depth, varying from 8-10 metres: but occasionally the formation may extend up to the lower limits of the littoral zone."

In Paterson Inlet, as far as is known, the " loose-lying formation " is composed of only one form, derived probably in an exactly comparable way from portions torn off by storms from the attached species of the sublittoral and deposited in these quiet waters, where, without becoming fixed, they continue to make apical growth, but not quite typically.

Previous Record.

It has not been possible to consult the original accounts of the Baltic and Adriatic formations, but it seems that loose-lying *Fuci* have been recorded much more commonly than loose-lying laminarians Frye (1914, p. 65) records that *Nereocystis* plants, torn loose and then tied to other plants, continue to grow; he illustrates by a photograph (Plate XXIII) continued growth in the holdfast of unattached *Nereocystis*.

For *Macrocystis* a comparable record is that of Skottsberg (1907, p. 93, Fig. 102), who describes and figures an abnormal bladderless form, found within Carenage Creek, Berkeley Sound, East Falkland Island. The depth was one metre, the bottom sand with shells, the water " bedeutend versüsst," and the place very sheltered. He adds (1941, p. 32): " We should expect the creek where the

stream empties to be brackish, and the salinity is probably low, but Berkeley Sound is wide and open, and there is quite some movement in the water outside, in Port Louis, so that conditions must be more favourable than expected." The specimen came from what is recorded as a "mixed *Codium-Rhodymenia* Association" with *Codium fragile, Ahnfeltia plicata,* and *Rhodymenia palmatiformis* abundant.

Of the specimen collected he says: "Haftorgane kamen leider nicht mit. Das wunderliche Aussehen rührt daher, dass die Kurzsprosse, als die Blasenbildung ganz ausblieb, die Fähigkeit der Verzweigung nicht verloren, die zuerst *Lessonia*-artig geschah und später zur Bildung von Langzweigen führte. Dieselben erreichen natürlich niemals den Wasserspiegel, denn der schwache Stamm vermag sie nicht emporzuheben. . . . Die allermeisten Blätter, die in normalen Fällen sich niemals teilen würden, haben hier kleine Spalten."

The Stewart Island specimens, except for the possession of bladders, often ill-developed, match this quite well, and the habitat is strikingly similar.

CONCLUSION.

It seems probable that a "loose-lying formation" dominated by *Macrocystis* is present in Paterson Inlet and possibly also in the arms of Berkeley Sound.

The specimens examined show the features typical of *limicola* forms in general—viz., vegetative reproduction, dwarf habit (in more delicate texture as well as in smaller size), excessive branching, and absence of attachment disc; but, like the Baltic loose-lying *Fuci*, they lack the tendency to spirality shown in the marsh forms. Marsh-inhabiting brown algae, comparable to those of Blakeney Point (Baker, 1912), Clare Island (Cotton, 1912) and other parts of European and American coasts, have not been recognised in New Zealand, nor have free-living types intermediate between marsh and submerged (Naylor, 1928) been noted here.

From analogy with other records of free-growing algae, and from the incipient branching observed in Wellington, usually in situations rather atypical for the species, it may be concluded that the branching form in Paterson Inlet has been developed directly from the attached plants of the outer coast, and therefore is a habitat form or ecad of *M. pyrifera*.

ACKNOWLEDGMENTS.

The material on which this discussion is based was acquired partly thanks to Mr Roy Traill's extensive and accurate knowledge of Paterson Inlet, partly through the help of the Biologist of the Marine Department, Mr. A. M. Rapson, who, at my request, kindly brought back specimens from Stewart Island, partly by the use of a boat very generously lent by the Wellington Harbour Board. All this assistance is most gratefully acknowledged.

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Figure 1.

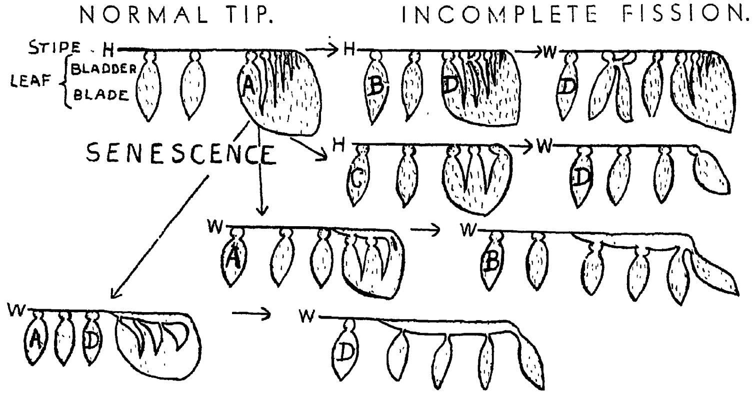


Figure 2.

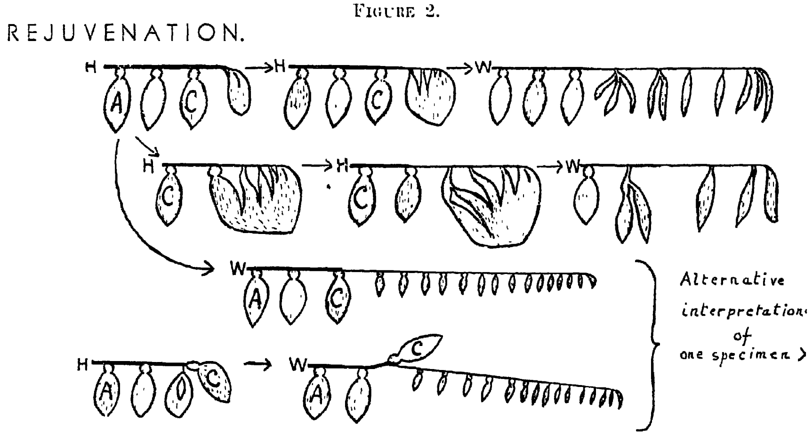
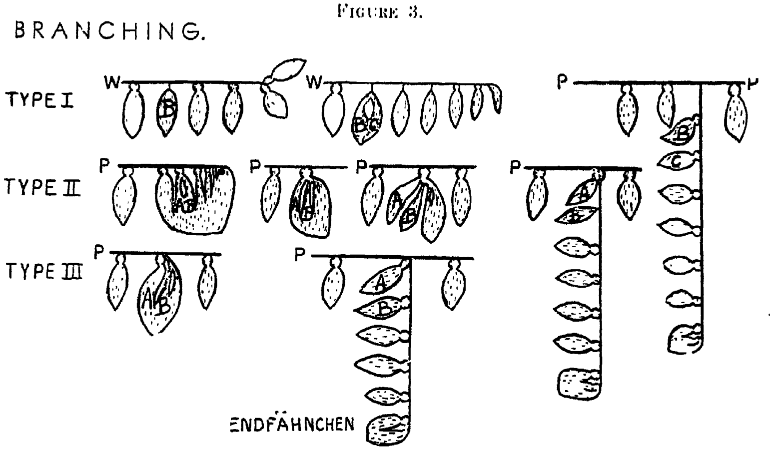
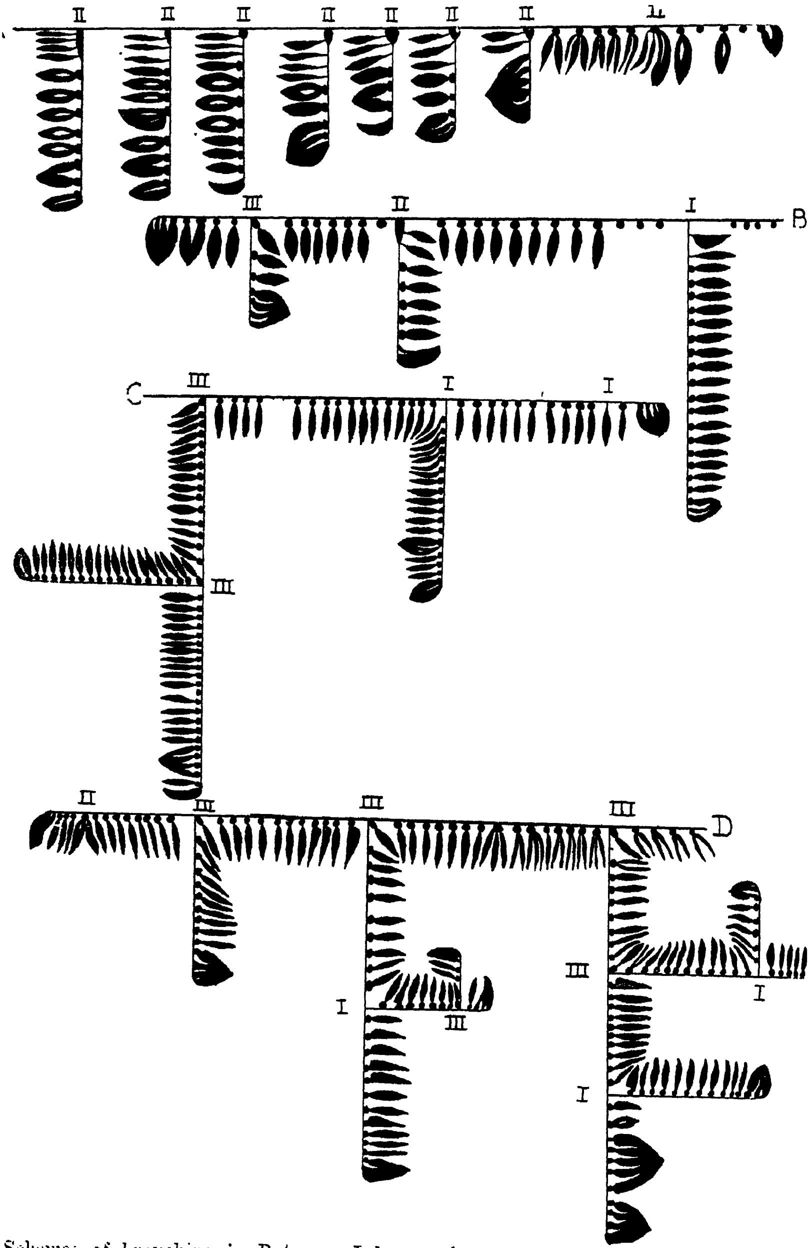


Figure 3.



The growth of the long frond of *Macrocystis pyrifera*.
W specimen from Wellington; P specimen from Paterson Inlet;
H hypothetical stage.

Figure 4.



Schemes of branching in Paterson Inlet specimens growing submerged in still water: types of branching described in text are indicated by Roman numerals.

Variation in *Senecio kirkii* Hook.f.

By F. J. NEWHOOK, Mycological Assistant, Plant Diseases Division, Department of Scientific and Industrial Research.

[*Read before Auckland Institute, October 29, 1942; received by the Editor, October 31, 1942; issued separately, March, 1943.*]

SUMMARY.

EVIDENCE is presented to show that *Senecio kirkii* is a compound species composed of a broad-leaved and a narrow-leaved variety between which occasional hybridisation occurs.

The narrow-leaved variety further shows local race formation.

In both varieties leaf outline, corolla shape, and sap colouration vary considerably.

INTRODUCTION.

Senecio kirkii is a shrub or small tree endemic to the North Island of New Zealand. It is common in hilly and wooded districts, occurring from near sea level to about 3000 ft. According to Cheeseman (1) the leaves are " very variable in size and shape " (Fig. 1).

The present paper records a detailed investigation to determine whether the variation is due to differences in habitat or whether more than one variety exists within the species.

Observations were made in the following regions: North Cape District, Waipoua Forest, Trounson Park, Waitakere Ranges, Rangitoto Island, Hunua Ranges, Coromandel Ranges, Mt. Te Aroha, Mt. Pirongia, Mt. Egmont, Waimarino, Urewera Country, and the Tararua Ranges.

GENERAL.

A—Ecological Aspect.

In the early stages of the investigation it was thought that the two forms might be epharmones, as in general, plants with broad leaves and plants with narrow leaves occupy different habitats.

In the Auckland district, plants with broad obovate leaves are almost always epiphytic, growing on *Cyathea* spp., *Dicksonia. squarrosa*, *Metrosideros* spp., *Collospermum hastatum*, *Freycinetia banksii* and moss and fern covered branches of large trees. Epiphytic plants of *S. kirkii* frequently attain large size. This is due in large measure to the presence of negatively geotropic adventitious roots which prevent the adult plant from falling away from its host (Fig. 3). The broad-leaved form thrives on the scoria of the Rangitoto Island lava fields, where other species normally epiphytic in rain forest also grow terrestrially. This form is strongly light-demanding, and it also requires a well-drained substratum such as is obtained in the epiphytic and lava field habitats.

The narrow-leaved form on the other hand is usually terrestrial and can tolerate rather more shade than the broad-leaved form.

Further investigation showed that the two forms were not epharmones:

1. Sometimes adult plants of both types grow together terrestrially (Fig. 2) and both may occur as neighbouring epiphytes under similar conditions (Figs. 3 and 4).

2. Notwithstanding changes in climate and habitat, leaves of both types are never found on the one plant. Several cases of natural transplanting have been observed, where a host plant bearing a broad-leaved *S. kirkii* has fallen to the ground. The epiphyte becomes truly terrestrial, yet the broad leaf-form is retained. With hemi-epiphytes the development of terrestrial rooting does not alter the leaf form.

3. The flowering seasons of the two varieties are different. Both epiphytic and terrestrial broad-leaved plants flower in spring and summer, while narrow-leaved plants in both habitats flower in autumn and early winter. (N.B. At Waipoua, in 1940, the narrow-leaved plants flowered in January, two or three months earlier than the normal time elsewhere. However, dead inflorescence stalks showed that the broad-leaved plants had flowered some time before this.)

Data appended to herbarium material in the Auckland Museum, the Dominion Museum, and the Botany Division (S. & I. R. Dept.), Wellington, support these observations which were made over three years.

4. In natural populations, leaves of seedlings are usually of the same type as those of adjacent adult plants.

Seeds from narrow-leaved and broad-leaved plants produced seedlings typical of the respective juvenile forms (see later). In this experiment seeds of each type were planted separately, at the same time and under similar conditions.

5. The broad-leaved variety is better adapted to withstand extremes of environment than the narrow-leaved variety.

(a) It can exist as an epiphyte in exposed positions.

(b) It is the form present on the exposed scoria of Rangitoto Island.

(c) On Mt. Te Aroha both forms occur together up to about 2000 ft. Above this altitude, to 3000 ft., only the broad-leaved form occurs.

(d) Comparable with (c) is the restriction of the narrow-leaved form to North of Lat. 38° S., while the broad-leaved form occurs over almost the whole of the North Island (see later).

(e) Broad-leaved plants are capable of a greater development of primary and secondary mucilage ducts and stone cells than narrow-leaved plants. These features in the cortex and pericycle of roots and stems are characteristic of xerophytic adaptation and would explain, in part, the ability of broad-leaved plants to grow as exposed epiphytes.

It is obvious that while different ecological conditions determine which variety will grow in a certain habitat, they do not cause the diversity of form.

B—Distribution.

The distribution of the two forms gives evidence of their distinctness.

North of Kaitaia, only the narrow-leaved form was seen (near Te Paki and Parengarenga, North Cape Area).

Both forms occur together from the Maungataniwha Ranges near Kaitaia, southwards to the Kaimai Ranges just north of Lat. 38° S.

From Mt. Pirongia (Lat. 38° S.) southwards, only the broad-leaved form occurs.

N.B. *S. kirkii* is apparently absent from the Waimarino Plateau, although only about 2,450 ft., where the low winter temperatures inland near the National Park accentuate the effects of altitude.

North of Lat. 36° S. (i.e., at Waipoua, Trounson and North Cape Area) all plants with narrow leaves bear a distinct hairy covering over the young stems and very young leaves. Broad-leaved plants of this region and plants of both varieties south of 36° S. are almost glabrous (Figs. 7 and 8).

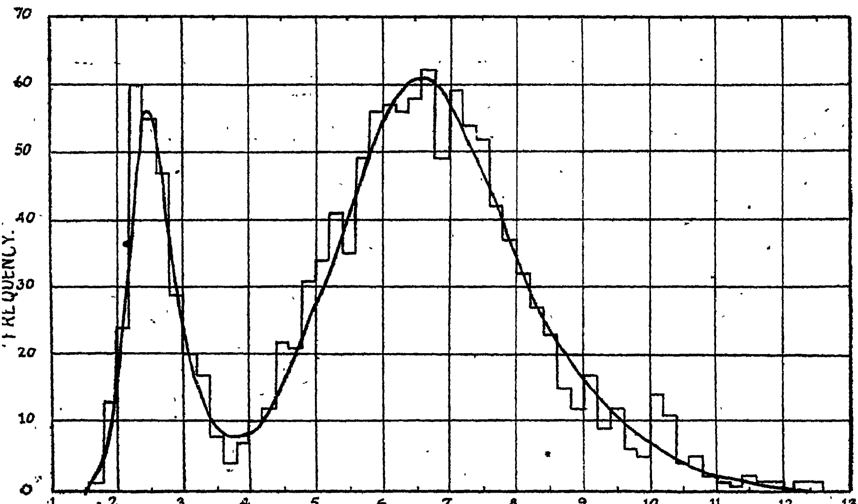
Cockayne (2) describes latitudes 38° S. and 36° S. as being the two most important " critical " latitudes limiting the distribution of plants in the North Island. It is significant that these latitudes are concerned in limiting the areas of distribution of the different forms of *S. kirkii*.

—*Metamorphosis.*

Seedlings from narrow-leaved plants have rather broad leaves at the base and show a gradual transition up the stem to leaves typical of the parent plant. Up to about twenty of these juvenile leaves are produced, the seedlings then being 3 to 4 inches high. These young seedlings are sometimes difficult to distinguish from those of the broad-leaved variety, but the first leaves of the latter usually narrow more abruptly to the petiole than do those of the former (Figs. 9 and 10).

When the leading shoot of a narrow-leaved plant is broken, new shoots which develop just below the wound frequently show a reversion to the rather broad juvenile form, with a fairly rapid transition to the typical leaf form (Fig. 5).

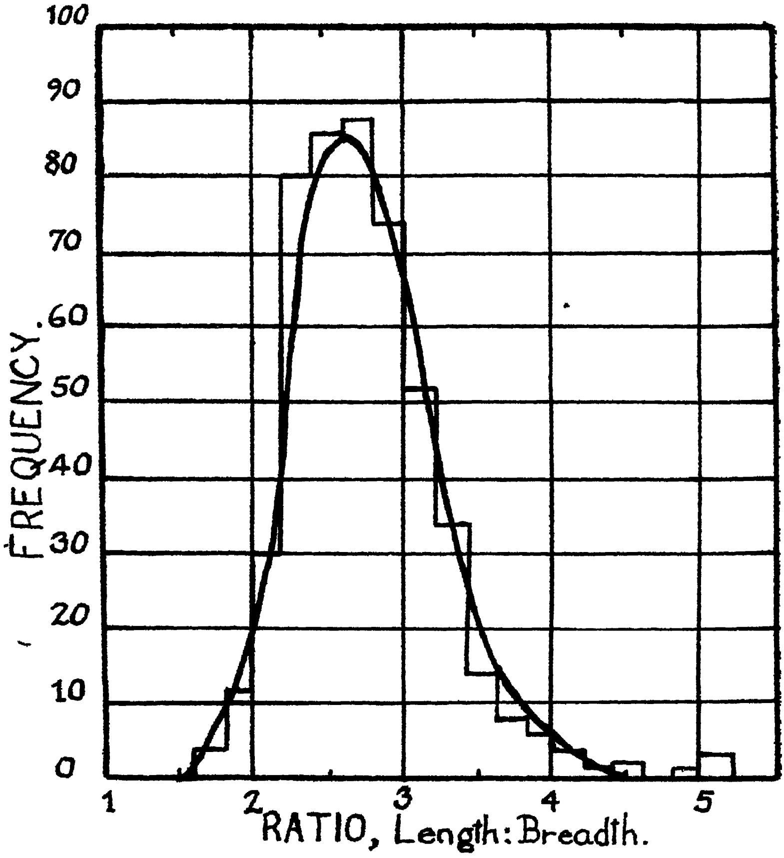
These are the only occasions on which individual plants show marked differences in leaf form.



TEXT FIG. 1.—Leaves from Waitakere Ranges.
Unit ratio—0.2. Number of leaves—1324.

D—Analysis of Leaf-form Variation in Natural Populations.

Method.—One leaf was removed from the centre of the leafy region of the nearest branch of each plant encountered in several populations of *S. kirkii.* The ratio of length to breadth was calculated for each leaf, and frequencies plotted against the ratios.



TEXT FIG. 2.—Leaves from Mt. Pirongia.
Unit ratio—0.2. Number of leaves—494.

Results.—The results show that for populations containing plants of both types two distinct curves are obtained, one with a mode approximately at ratio 2.5 and the other at about 6.5 (Text Fig. 1).

For populations with only broad-leaved plants, a single curve is obtained, the mode again being about 2.5 - 2.7 (Text Figs. 2 and 3).

When leaves of epiphytes only or terrestrial plants only are considered, a curve with two peaks of similar location to the above is obtained in each case, indicating that the leaf form is independent of the epiphytic habit.

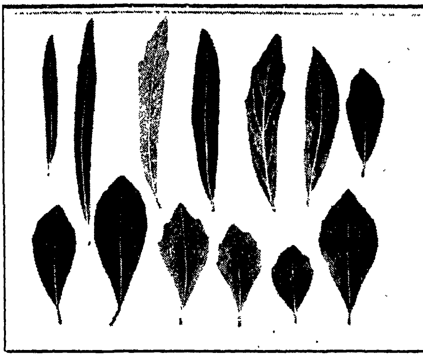


FIG. 1.—Leaf variation in *Senecio kirkii*—leaves from Waitakere Ranges.

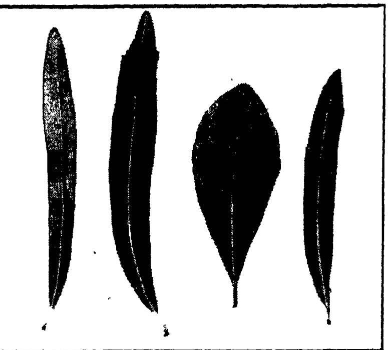


FIG. 4.—One leaf from each of four epiphytes on the tree-fern. Left to right in order upwards from base.

FIG. 2.—Broad- and narrow-leaved plants growing together terrestrially.

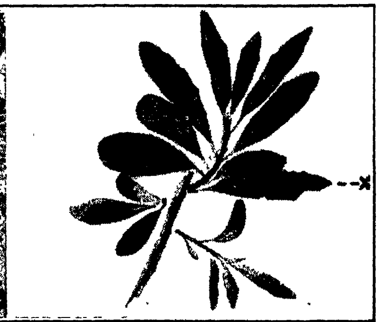


FIG. 5.—Reversion shoots after death of main shoot, narrow-leaved *S. kirkii*. Original leaf of shoot at X.

FIG. 3.—Narrow-leaved *S. kirkii* epiphytic on *Dicksonia squarrosa*. Note negatively geotropic root.

FIG. 6.—Two types of corolla shape from narrow-leaved *S. kirkii* with similar leaves and from similar

FIG. 7.—Maximum development of hairs on *S. kirkii* from Waitakere Ranges.

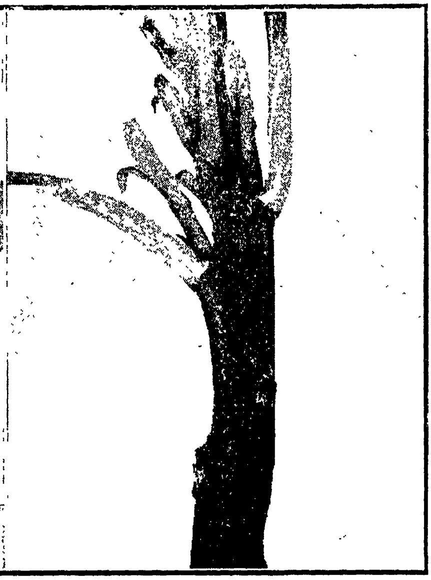


FIG. 8.—Normal development of hairs on narrow-leaved *S. kirkii* North of Lat. 36° S.

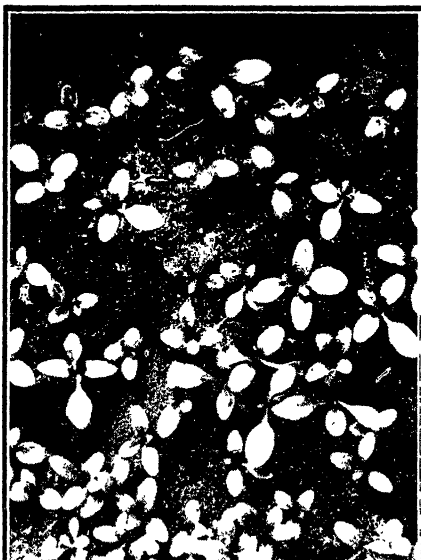
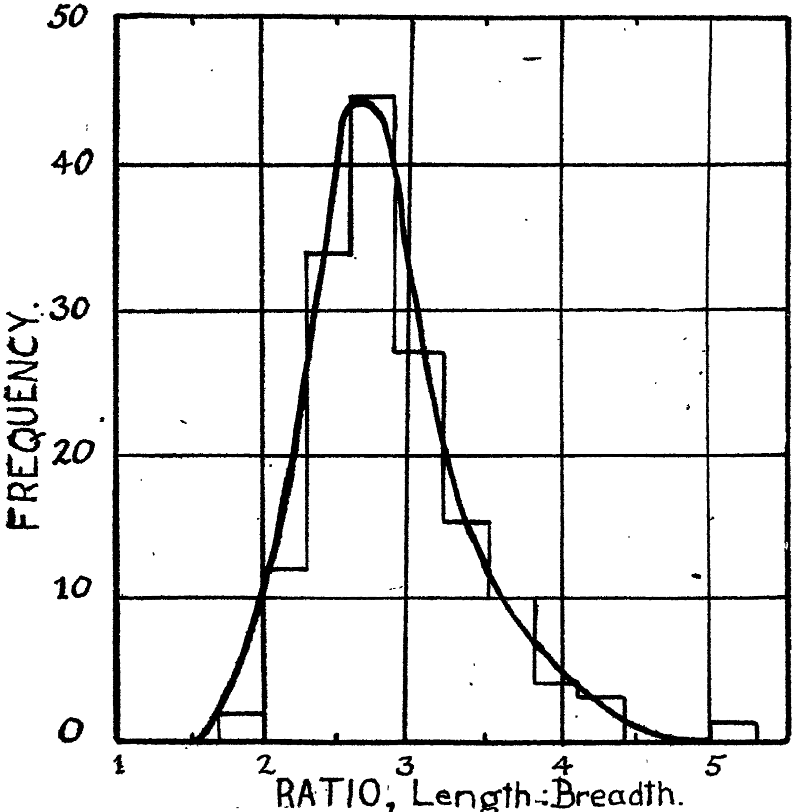


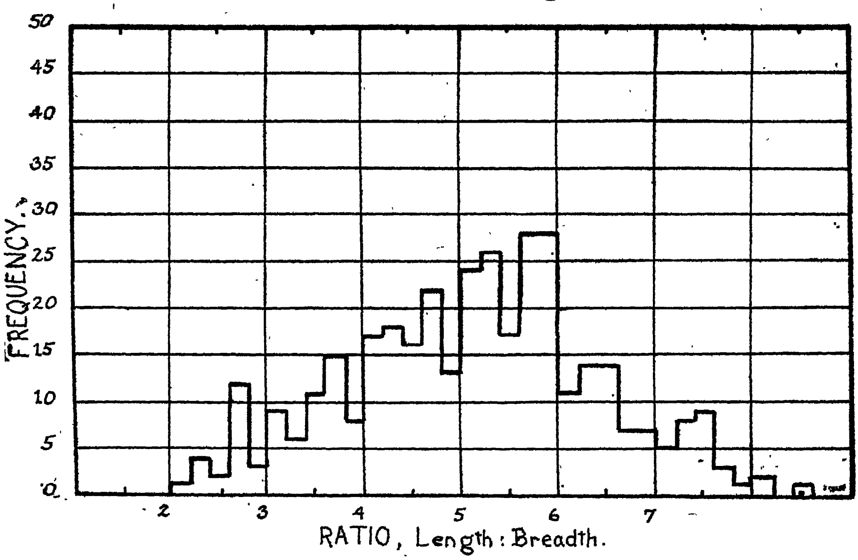
FIG. 9.—Seedlings from narrow-leaved *S. kirkii*.

FIG. 10.—Seedlings from broad-leaved *S. kirkii*.



Unit ratio—0.3. Number of leaves—153.

TEXT FIG. 3.—Leaves from Tararua Ranges.



Unit ratio—0.2. Number of leaves—324.

TEXT FIG. 4.—Leaves from hybrid swarm Orara

Frequency ratio graphs for all the leaves from individual plants of *S. kirkii* were simple normal curves showing no greater variation than that in other species examined.

Conclusion.—The analysis of leaf-shape variation in natural populations shows that there are two constant and distinct forms of *S. kirkii.*

E—Hybridisation.

In April, 1940, near Orere in the Hunua Ranges, a few broad-leaved plants were flowering at the same time as the narrow-leaved plants. On a ridge in this district there occurs what appears to be a typical hybrid swarm covering a few square chains. Text Fig. 4 illustrates the curve obtained from material of this region. This curve indicates that a large number of the plants in the swarm are of intermediate type between the typical narrow and broad-leaved forms. The comparative lack of the latter is due to there being no large trees and few tree ferns for broad-leaved epiphytes to become established.

In the Waitakere Ranges occasional small groups of plants show rather intermediate form. Isolated plants of each type have been observed flowering between the normal flowering seasons, and though infrequent, these may provide the means for occasional hybridisation.

F—Minor Variation.

(a) The *leaf margin* in both forms varies from almost entire to sinuate, coarsely serrate or dentate (Fig. 1). Seedlings from one parent plant may vary in this respect.

(b) *Corolla shape.* Fig. 6 shows the inflorescences from two neighbouring plants with almosts identical leaves. Such differences in corolla shape are occasionally to be found in plants of both varieties.

(c) *Development of purple sap pigment.* Plants of either type, even when growing alongside one another, vary in the amount of pigment produced on leaves and young stems in strong light.

(d) In addition to having tomentum on young stems and leaves, many of the plants (all narrow-leaved) at Te Paki, in the North Cape Area have rather oblong leaves with the blade narrowed abruptly to a very short petiole. These leaves are further crowded into compact "rosettes" at the ends of the branches, the two features together constituting a distinct local characteristic.

Acknowledgments.

Thanks for helpful criticism during the research are due to Professor T. L. Lancaster and Mr L. H. Millener of the Auckland University College, and to Mr. J. C. Neill and Dr. W. D. Reid of the Plant Diseases Division, S. & I. R. Department, Auckland, for similar help during the writing of the paper.

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The Geology of the Brocken Range and the Kaiwhata Valley, East Wellington.

By D. A. BROWN, New Zealand Geological Survey.

[*Read before Wellington Branch, October 9, 1941; received by the Editor, November 24, 1942; issued separately, March, 1943.*]

PRIOR to his departure for England, the writer was enabled by the courtesy of Mr. A. W. Daysh, of Masterton, and Mr. and Mrs. Elliott, of Ngahape, to spend five days during August, 1941, near the Brocken Range, which lies about 15 miles south-east of Masterton. In the short time, no detailed work was possible, but, as the district is exceedingly interesting, the following notes may have value as a nucleus for later detailed surveys. During his visit, the writer made his headquarters at Ngahape, a settlement 19 miles (by road 28 miles) south-east of Masterton.

The petrology of the igneous rocks collected is described by Dr. C. O. Hutton in the paper following this one (pp. 353–370).

Previous Work in the Area.

The district has been little studied in the past chiefly on account of the difficulty of access. The area here described forms part of four survey districts, Otahoua, Rewa, Wainuioru, and Kaiwhata in the Wellington Land District.

The first record of geological investigation is that given in 1861 by James C. Crawford, the Wellington Provincial Government geologist. He described the precipitous and jagged hills " on a line parallel to the East Coast, and perhaps at a distance of ten miles from it " as composed of stratified and tilted sandstones. The Brocken Range is composed of a group of these " taipos," so-called by the Maoris, who held them in superstitious dread as the dwellings of evil spirits. Crawford noted that they were intruded by igneous rocks, which he called " trachytes," and also described pebbles of the same rock from the bed of the Upokongaruru Stream, which flows from the western slopes of the Brocken Range. He noted that this " trachytic " rock decomposed into an iron sand, and " in it Mr. Haast has discovered a speck of gold with the microscope."

In 1883, McKay visited the East Coast District of Wellington Province, and a year later published a short paper on the igneous rocks. In it he mentioned a later, fuller report; but this does not seem to have been published. He noted the frequent occurrence of igneous rocks on the coast from Castle Point southwards, and drew attention to the " syenitic and porphyritic " rocks brought down by the Kaiwhata River. He searched in vain for the source of these igneous boulders, but on information received from Mr. Beetham, M.H.R., he found a large outcrop of the rocks in the headwaters of the Upokongaruru Stream on the eastern part of the Brancepeth run. This, however, did not explain the presence of coarse, crystalline igneous rocks in the Kaiwhata River, for the Upokongaruru is a tributary of the Pahaoa River, a stream farther to the south. McKay recognized this fact, and added a note that Mr. Beetham had informed him that such igneous rocks traversed the old sandstones on the north-east. An examination of the Te Maire Stream or the Totara

Stream would have shown him that the igneous boulders do not come down either of these valleys, the only channels along which they could reach the Kaiwhata River from the Brocken Range.

The explanation was partly given by McKay's son, W. A. McKay, in 1899, when he recorded the presence of igneous intrusions and tuffs first, in the Kaiwhata river-bed about a mile below its junction with Bismarck Creek and second, near the confluence of the Te Maire and Kaiwhata. W. A. McKay spent two or three days in the Kaiwhata Valley in very bad weather during the early part of 1899, and he has given a good account of his work there.

The present writer found another completely independent intrusion of coarsely crystalline igneous rocks, which crosses the Kaiwhata Stream a quarter of a mile east of Ngahape.

The regional examination by the officers of the N.Z. Geological Survey in Eketahuna Subdivision to the north has not yet been extended into the Brocken District; but much of the geology of the latter can be correlated with that of the former area.

Geology.

(a) *The Brocken Range and Environs.*

The Brocken Range is an easterly offshoot of the Maungaraki Range, which runs south-westward, parallel with the east coast and ten to twelve miles distant from it. The Brocken Range splits off near Rewa Hill and lies about halfway between the coast and the Maungaraki Range. The portion investigated lies to the south of the Fernyhurst Road, and includes the prominent peaks Te Maipi, Pukekowai, and Puketeitei rising to elevations of 1500–1600 ft. above sea-level. These peaks are jagged and precipitous "taipos"; and Te Maipi is almost inaccessible except from the south side. They form open grass country with small patches of native bush near the tops. The range is composed of hard, moderately coarse, indurated and shattered greywacke (P.7599, 7604*) which Ongley (1935) has correlated on lithology with the Taitai formation of the Waiapu Subdivision. The line of peaks seems to follow strike ridges of harder components of the formation.

This greywacke also forms the lower country on the east side of the range between it and the Kaiwhata and Te Maire Streams. Here again are the peculiar ridges and "castles" resembling basalt plugs or necks (see Fig. 3). The reason for their resistance to erosion is not known, as on examination their component material appears to be identical with that of the surrounding rocks. Such, for example, is the "Sugarloaf," 780 ft. high on the north side of Totara Stream (P.7598).

On the north bank, near the junction of Totara and Te Maire Streams, a few small, well-rounded pebbles of porphyritic igneous rock (P.7617) were discovered in the weathered sandstone, thus supporting, but not proving, the correlation with the Taitai formation, which farther to the north contains numerous bands of igneous conglomerate.

* The numbers prefixed by "P" refer to specimens in the rock and mineral collections of the N.Z. Geological Survey.

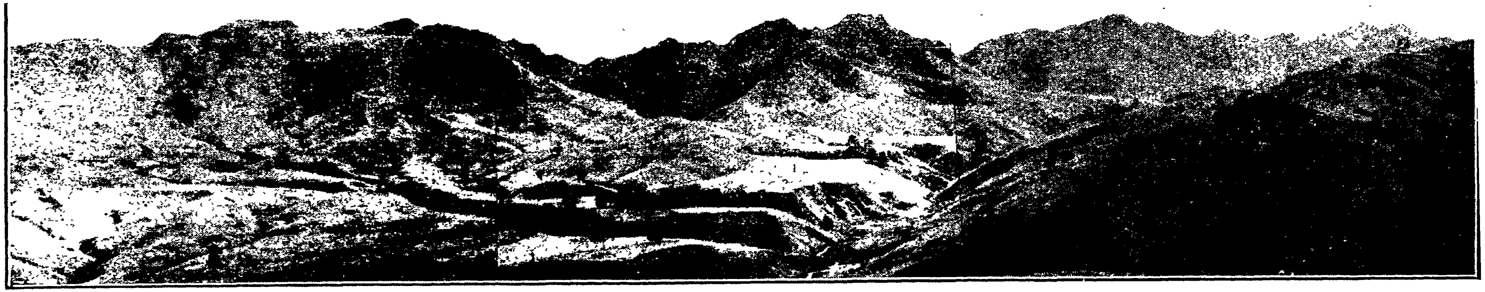
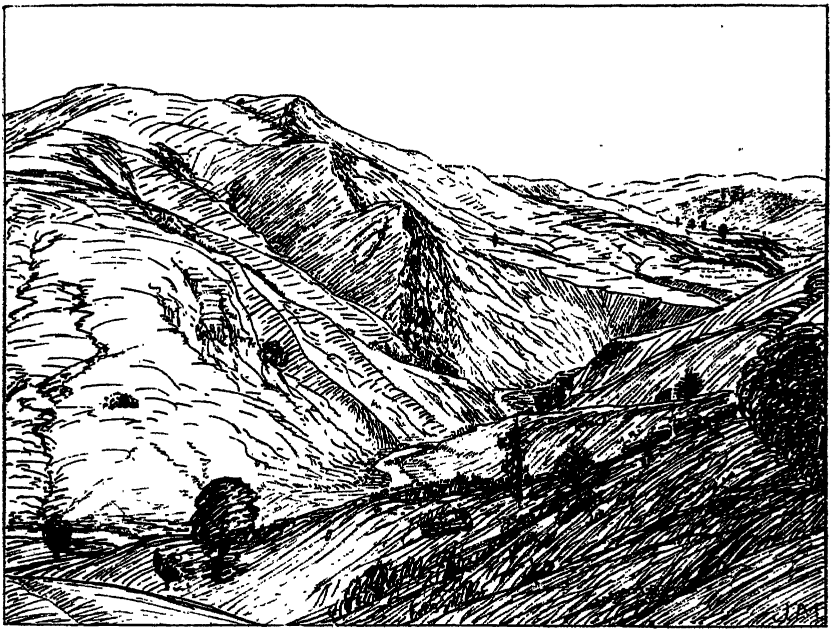


Fig. 1.
East side, Brocken Range, from Sugarloaf. Te Maipi in centre, Pukekowai to left, with Bancepeth Pass between. Te Maire Stream in foreground.

Fig. 2.
West side, Brocken Range, from Te Maipi. Pukekowai to left, Tertiary limestone scarp running from middle distance to extreme right, and Red Hill teschenite in low rounded hill near right-hand border. Maungaraki Range in the background.

Fig. 3.
Sugarloaf Hill, a prominent greywacke residual near Ngahape. Brocken Range in the background.



Text Fig. 1.
Looking east up Kaiwhata Valley. The sill forms the prominent outcrop intersecting the opposite slope and forming a V pointing down-valley.

The most interesting feature and the main purpose of the trip was to discover the source of the teschenite pebbles and boulders found by McKay (1884) in the Upokongaruru Stream near Red Hill, on the Brancepeth run, and briefly described by Sollas (1906).

Between Pukekowai and Te Maipi is a low pass about 1200 ft. high over which runs a well-formed track. Passing from east to west, one descends into a hollow formed by the headwaters of the Upokongaruru Stream, evidently part of McKay's "crater" (1884), but in fact, merely the breached hollow between two greywacke strike ridges.

Abutting sharply against the greywacke about half a mile north-west of Pukekowai and on the south side of the Upokongaruru is a ridge of dark-brown, moderately soft quartz sandstone (P.7611), capped by 4–5 ft. of extremely hard coquina (P.7600) (a detrital limestone composed chiefly of molluscan shells) dipping at 25° to the west. This latter rock closely resembles the Ugly Hill limestone (Ihungia) of the Dannevirke Subdivision.

On the north side of the stream the igneous intrusion was discovered. This is evidently McKay's Red Hill; and it is composed entirely of coarsely crystalline basic igneous rock, a melanocratic teschenite (P.7616). From the scattered boulders of igneous rock aligned in a ridge on the south side of the Upokongaruru, it appears that here is a small dyke of teschenite which has altered sediments of the Taitai formation (P. 7606, 7613).

The main intrusion appears to be roughly circular. The rock on decomposing gives rise to a green, sandy soil (P.7610), and the

mass extends for about 20 chains north of the Upokongaruru Stream to a point almost due west of Te Maipi, where it is seen in contact with the greywacke.

The coarse texture of the igneous rock indicates a hypabyssal intrusion, the age of which is doubtful. The intrusion has certainly altered the older greywacke and argillite, but does not appear to have affected the younger (? Ihungia) sandstone and limestone, which seem to have attained their present position by fracturing along a line west of the Red Hill igneous mass. Hence the teschenite is post-Taitai (Upper Mesozoic) and probably pre-Ihungia (Lower Miocene) in age.

(b) *The Kaiwhata Valley.*

The Kaiwhata River drains the low country situated between the Brocken Range on the west and the coastal range on the east which runs south-south-west from the Mataikona River in Eketahuna Subdivision. The Kaiwhata Stream drains the western slopes of this latter range and flows westwards to Ngahape, where it is joined by the Kopi, Te Maire, and Totara Streams. From this point for a further six miles it travels south along the general strike of the country as a stream of considerable size; again it turns at right angles, and cutting through the coast range in a deep gorge, discharges on the east coast about eight miles south of Uruti Point.

The drainage system is now deeply entrenched owing to uplift, whilst deforestation has greatly increased erosion. In the lower Kaiwhata Valley south of Ngahape there is a prominent, high-level terrace representing a former erosion level, protected now by the rock barrier of the coastal range, which is composed of white, pink, and grey fine argillites of the Whangai formation.

Time permitted of only a rapid reconnaissance of the Kaiwhata Stream east of Ngahape; but the information gathered may be of value.

At the stream junction about two miles east of Ngahape the stream cuts through well-bedded, fine, micaceous, black argillites and sandstones (P. 7612), which are twisted and shattered by faulting. The rocks strike about south-west and dip generally to the north-west, but are often vertical. These beds are probably of Tapuwaeroa or even Raukumara age, and their attitude suggests a strong fault between this point and the coast range.

Downstream the dips flatten somewhat, and the strike swings to the west. Half-a-mile west of the junction, near the old woolshed on the north bank, the first of a series of conglomerate bands appears with pebbles of greywacke up to 2 in. in diameter. No igneous pebbles were seen. This is followed by a set of fine bedded sandstones, 25 ft. thick, dipping 40° to the north and overlain in turn by another coarse conglomerate. A small fault here brings fine black mudstone into juxtaposition with the conglomerates. This mudstone contains *Inoceramus (Callistoceramus) bicorrugatus* Marwick (P.7603), the characteristic fossil of the Mangaotane mudstone (Raukumara Series).

The succession continues downstream with alternating mudstones and sandstones and occasional thick conglomerate bands, the grade of the pebbles in the latter appearing to decrease as the beds become younger.

The Kaiwhata Sill (See Sketch Map).

In the Kaiwhata Stream, about 20 chains upstream from the Ngahape bridge, the stream intersects a large sill of hard, crystalline, dolerites weathering in cuboidal blocks (P.7602). The sill appears here to be about 20 ft. thick, though contacts with the neighbouring rocks were not seen.

The reason for calling this igneous mass a sill is due to its attitude seen from the hills above the stream. It stands out as a hard erosion remnant amongst the softer sandstones and mudstones, and is seen to conform closely with the bedding of the latter, and follows the inclined V-shape of the valley. That it is not a flow is indicated by outliers above the next succeeding sedimentary rocks.

The writer followed the sill exposures for about a mile and a-half to the north-east, but owing to the limited time did not go further, though the indications were that the sill is exposed for a long distance farther north-east. McKay (1899) noted that an intrusion crossed the Kaiwhata River a mile below the junction with Bismarck Creek; this is on a projection of the line of the Kaiwhata sill and two miles south of its intersection with Kaiwhata Stream.

The igneous rock forms prominent buttresses, and in exposures to the north of Kaiwhata Stream is extremely coarse-grained with long fibrous crystals of feldspar and clinopyroxene (P.7607, 7615).

Downstream from the sill the mudstones and sandstones continue, and at the junction of the Kaiwhata and Kopi Streams there is a thick bed of soft greensand (P.7609). Westward to Ngahape the beds are highly glauconitic.

West of the Kaiwhata and Te Maire, greywacke and indurated sandstone form prominent hills such as the Sugarloaf. This is strong evidence for a fault running approximately north and south along the line of the Kaiwhata Valley; but owing to the lack of data its position is ill-defined.

Ngahape Intrusion.

On the Kaiwhata Valley road about 200 yards north-west of Ngahape School is a large outcrop, 100 yards long and 30 ft. high, of black, zeolitic, moderately fine-grained variolite displaying pillow forms in one or two places (P.4886–4893; P.7608). It intrudes sandstone and argillite (? Tapuwaeroa), pieces of which form large hornfelsed xenoliths in the cliff exposure (P. 7614). The rock is deeply weathered and is traversed by thick veins of calcite (P.7605). This mass was first noted by W. A. McKay (1899), and was recently visited and sampled by Mr. I. J. Pohlen, of the Soil Survey Department. The upper part of Cemetery Hill, of which the igneous rock forms the lower slopes, is composed of pink and yellow fine argillite.

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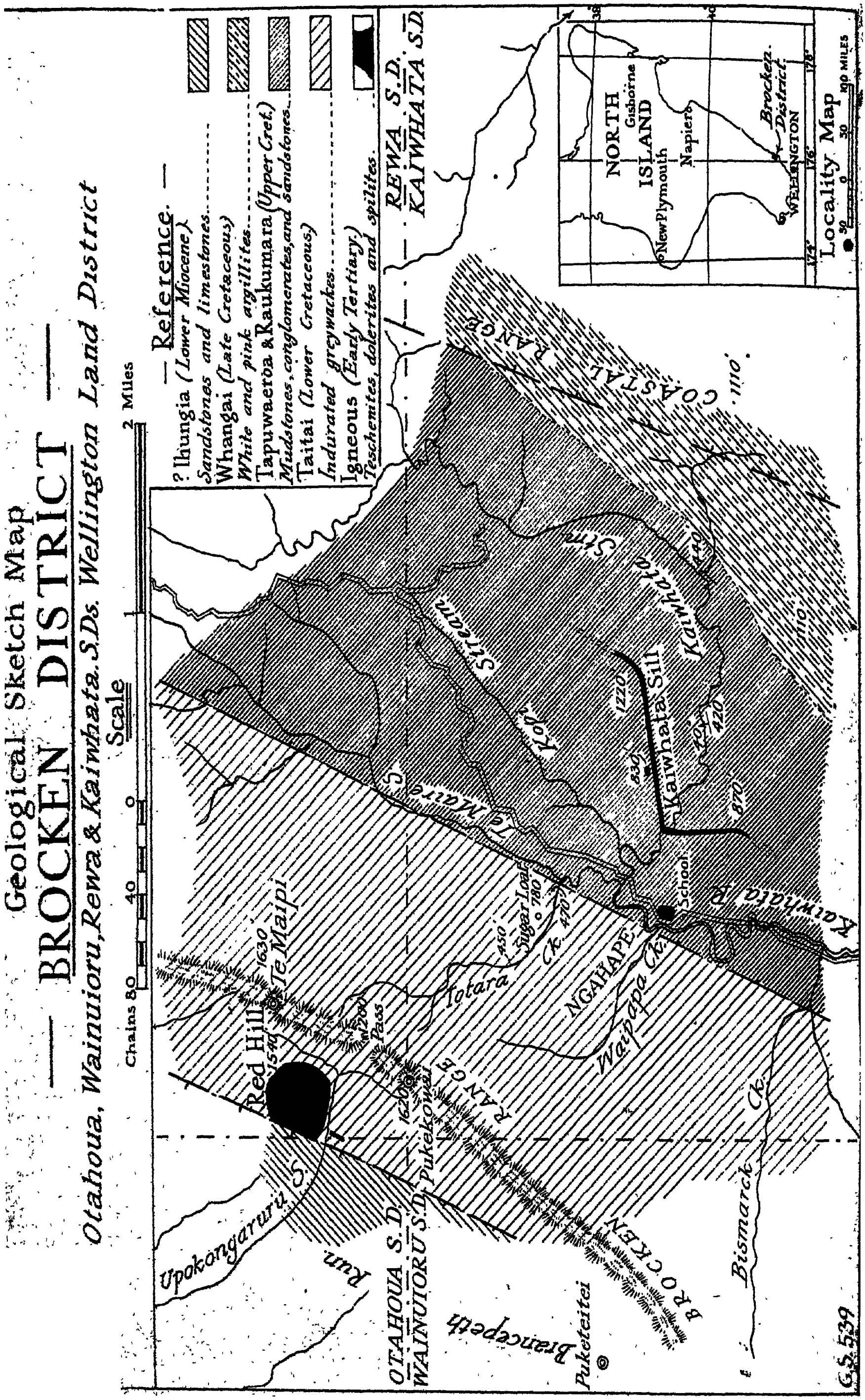
Geological Sketch Map
— BROCKEN DISTRICT —
Otahoua, Wainuioru, Rewa & Kaiwhata. S.Ds. Wellington Land District
Scale
Chains 80 40 0 1 2 Miles
— Reference —
? Ihungia (Lower Miocene) Sandstones and limestones
Whangai (Late Cretaceous) White and pink argillites
Tapuwaeroa & Raukumara (Upper Cret.) Mudstones, conglomerates, and sandstones
Taitai (Lower Cretaceous) Indurated greywackes
Igneous (Early Tertiary) Teschenites, dolerites and spilites
REWA S.D.
KAIWHATA S.D.
OTAHOUA S.D.
WAINUIORU S.D.
NORTH ISLAND
Gisborne
Napier
New Plymouth
WELLINGTON
Brocken District
Locality Map
COASTAL RANGE
BROCKEN RANGE
Red Hill
Te Maipi
Pass
Pukekowai
Sugar Loaf
Totara Ck.
NGAHAPE
Waipapa Ck.
Te Mairo S.
Kaiwhata Sill
Kaiwhata Stream
Kaiwhata R.
School
Upokongaruru S.
Run
Brancepeth
Puketeitei
Bismarck Ck.
G.S. 539

The Igneous Rocks of the Brocken Range-Ngahape Area, Eastern Wellington.

By C. O. HUTTON, Petrologist, New Zealand Geological Survey.

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INTRODUCTION.

In this paper are embodied the results of a mineralogical and petrological investigation of the igneous rocks of the Brocken Range—Ngahape area, Eastern Wellington. The geology of this area has recently been studied by Mr. D. A. Brown (1943) and the rocks herein described were collected by him. At his request this study was undertaken, and it is divided into three parts—viz., mineralogy, petrography, and petrogenesis.

MINERALOGY.

Two minerals, a pyroxene and an ore, have been separated in the pure state from the teschenite of Red Hill (P. 7616) by centrifuge and electro-magnetic methods. For the final stages of purification the two minerals were crushed finely in an agate mortar, and the powders thus prepared were centrifuged in order to free the products from inclusions. The two minerals were analysed by Mr. F. T. Seeyle, of the Dominion Laboratory.

Diopsidic augite:

The refractive indices were determined in sodium light and the accuracy is considered to be $\pm$ 0.002. The optic axial angle and extinction angle were determined on the Federov universal stage, and for the latter determination Nemoto's method (1938) was used.

Chemically the clinopyroxene is a diopsidic type low in sesquioxides, and if the latter are disregarded as recommended by Hess (1941, pp. 516-517) the mineral may be considered as a member of the wollastonite, clinoenstatite, clinoferrosilite, ternary system. Calculated as such, the pyroxene has the approximate composition of Wo 49, En 37.7, Fs 13.3 (weight per cent.) and lies close to diopside, the mid-point of the CaSiO — $MgSiO_3$ join. When plotted on Hess's diagram (1941, p. 518) the pyroxene falls into the field of salite. Plotting a pyroxene of this composition on the diagrams prepared by Deer and Wager (1938, p. 20) and Wager and Deer (1939, p. 80) a satisfactory comparison of the observed optical constants is noted.

TABLE I.—ANALYSES OF DIOPSIDIC AUGITES.

	A.	B.	C.	D.	E.
SiO_2	49.57	50.39	51.05	51.05	50.10
Al_2O_3	3.82	3.54	5.23	1.80	4.57
Fe_2O_3	2.00	1.95	0.96	2.03	2.34
FeO	6.59	8.47	7.35	6.56	7.14
MgO	13.75	15.82	14.18	13.82	14.20
CaO .	21.44	18.41	19.10	22.06	20.18
Na_2O ..	0.69	0.70	0.39	0.38	0.32
K_2O ..	0.08	0.14	0.07	0.08	tr.
H_2O +	0.10	0.11	0.50	0.17	0.24
H_2O −	0.02	0.04	0.50	0.04	0.10
TiO_2 ..	2.05	0.87	0.50	0.36	0.70
P_2O_5 .	nt. fd.	—	tr.	0.46	—
MnO .	0.13	0.19	0.25	1.22	
NiO	0.04	—	—	—	
V_2O_5 ..	0.045	—	—	—	
	100.[illegible]	100.[illegible]	100.09	100.0[illegible]	100.2
α	1.690	1.684	—	1.684	1.684 − 1.700
β .	1.697	1.692	—	1.691	1.692 − 1.708
γ	1.715	1.712	—	1.712	1.707 − 1.721
$\gamma - \alpha$	0.025	0.028	—	0.028	0.020 − 0.021
Pleochroism	very weak	weak	—	—	—
2V	52 − 54°	46°	58°	60°	50° 41′ − 57° 55′
$Z \wedge c$	42°	39°	40°	41°	40° − 43°
Dispersion	r > v	r > v	—	—	—
Sp. Gr.	3.34	3.35	—	3.370	—

A. Diopsidic augite from teschenite, P.7616, Red Hill, Rewa S.D., Wellington Land District. Anal.: F. T. Seelye.

B. Augite from Ivnarmiut, East Greenland, Wager and Deer (1939, Table 19, No. 6, p. 152). Anal.: W. A. Deer.

C. Augite from Co. Antrim, Ireland, Harris (1937, P.102). Anal.: W. H. Herdsman. Harris's total is incorrect.

D. Diopside from phenocrysts of Treasure Mountain quartz latite, 5 miles S.E. of Del Norte, Colorada, Larsen, Irving, Gonyer and Larsen (1936, Table 2, No. 1, p. 695). Anal.: F. A. Gonyer.

E. Augite from Yoneyama, Etigo, Japan, Kuno and Sawatari (1934). Anal.: S. Tanaka.

XY $(Si,Al)_2$ $(O,OH,F)_6$ has been suggested by Machatschki (1929) as the general formula for monoclinic pyroxenes, and a recalculation of analysis A in Table I on this basis is presented in Table II. As will be seen the requirements of this formula appear to be completely fulfilled. Most of the aluminium is required in the four co-ordinated position in order to satisfy the silicon chains of the pyroxene structure, while 0.0158 aluminium ions remain in six-fold co-ordination. The vexed question of the correct allocation of the titanium does not, therefore, arise, as this ion is included in the Y group of Machatschki's formula.

TABLE 2.—CALCULATION OF THE FORMULA OF CLINOPYROXENE.

	Wt. per cent.	Mol. ratios.	No. of metal atoms on the basis of 6 (O.OH).		
SiO_2 ..	49.57	0.8253	1.8480		2.00
Al_2O_3 ..	3.82	0.0375	0.1678	0.1520 / 0.0158	
TiO_2 ..	2.05	0.0257	0.0575		
Fe_2O_3 ..	2.00	0.0125	0.0559		
FeO ..	6.59	0.0917	0.2052		
MnO ..	0.13	0.0018	0.0040		2.01
MgO ..	13.75	0.3410	0.7633		
CaO ..	21.44	0.3823	0.8557		
Na_2O ..	0.69	0.0111	0.0497		
K_2O ..	0.08	0.0009	0.0040		

The formula is thus:—

$$(Mg,Fe'', Fe''', Ca,Mn,Na,K,Ti,Al)_2 \; [(Si,Al)_2 \; O_6]$$

Iron-ore:

TABLE 3.—ANALYSES OF TITANIFEROUS IRON-ORES.

	A.	B.
FeO	32.30	34.9
Fe_2O_3	21.93	18.6
TiO_2	38.33	46.1
Al_2O_3	0.70	—
MgO	3.03	—
MnO	0.49	—
NiO	0.03	—
V_2O_3	0.23	—
SiO_2	2.63	0.7
CaO	nt. fd.	—
H_2O at 105° C.	0.25	—
	99.92	100.3

A. Titaniferous ore from teschenite, P.7616, Red Hill, Rewa S.D., Wellington Land District. Anal.: F. T. Seelye.
B. Fine-grained ilmenite-haematite intergrowth, containing blebs of inter-grown rutile and titaniferous magnetite, Weld Range, Murchison, Western Australia, Edwards (1938, p. 41). Anal.: E. S. Simpson.

The ore in the teschenite occurs in abundant idiomorphic grains, and because the analysis of the rock itself showed a high figure for TiO_2 the ore was separated and analysed. An examination of a polished surface of teschenite revealed that the iron-ore is composite in nature, probably consisting of ilmenite set in a base of haematite. As pointed out by Edwards (1938, p. 43), this type of intergrowth would result from a gradual unmixing if cooling was slow enough. This unmixing would bring about the formation of two solid solutions, one rich in Fe_2O_3 and the other in $FeTiO_3$. Actually the solid solution, rich in Fe_2O_3, would, according to Ramdohr (1926, p. 357) contain just under 10 per cent. of TiO_2 if homogeneous. The MnO and MgO in the ore will presumably take the place of ferrous iron.

Fibrous zeolites. Thomsonite, with very minor natrolite, is well developed in the teschenites (P. 3230, 3231, 7616) as sheaf-like

aggregates of sharply acicular crystals. Thomsonite is colourless, with straight extinction and elongation of the needles parallel to β; refractive indices have been determined as follows:—

$$\alpha = 1.513 \pm 0.002$$
$$\beta = 1.516$$
$$\gamma = 1.522$$
$$\gamma - \alpha = 0.009$$

$2V = 68° \pm 2°$. Therefore, according to curves drawn up by Winchell (1933, p. 388), the mineral should contain approximately 37–38 per cent. of the $Na_3Ca_9Al_{19}O_{80}.24H_2O$ molecule; or should give an analysis somewhere intermediate between Hey's analyses Nos. 1 and 2 (1932, p. 54, Table I).

Intimately associated with the radiating aggregates of thomsonite is a very minor amount of a zeolite with fibres positively elongated; birefringence is about 0.012 and $\gamma = 1.485$. The mineral is believed to be natrolite. Microchemical tests do not indicate any more than traces of K_2O in these zeolites, hence the thomsonite differs from that investigated in a somewhat similar rock from Waihola, East Otago (Hutton, 1942, pp. 181–182).

Amygdule mineral. In a group of variolitic pillow-lavas a green micaceous mineral forms amygdaloidal infillings and also some of the base or mesostasis. It is very minutely crystalline and occurs in aggregates of flakes, while the entire infillings occasionally measure as much as 2 mm. The colour varies from a greenish blue, through glaucous green to a rusty brown tint. Commonly a zonary structure is observed in the vesicles, usually with the olive-green material lining the walls of the amygdules, this material giving place in the centre to the greenish-blue phase. The brown material occurs in any position relative to the green varieties. Refractive index tests show that the composition must vary considerably, for values from 1.588–1.615 were determined for γ. Data determined on a single platelet are as follows:—

α = 1.590
γ = 1.610
Elongation: positive
α = pale green
$\beta = \gamma$ = greenish blue

Qualitative microchemical tests show that (OH), Fe'', and Mg are the chief constituents; Al_2O_3, Fe''', and K_2O appear to be of minor importance only.

Although the optical properties of the mineral are somewhat similar to those of bowlingite, the comparison ends there, for bowlingite appears to have much higher birefringence, and, furthermore, it is usually a product of alteration of olivine. It is believed that the amygdule mineral is a product of crystallisation of a ferruginous gel and that it does not represent direct decomposition of ferromagnesian minerals. Actually the mineral is comparable to Jolliffe's mineral X (1935, pp. 411-412), shown by analysis

(*loc. cit.* p. 416) to be a hydrated silicate of magnesium and iron, with most of the iron in the ferrous condition. On the other hand, the colour, pleochroism, and mode of occurrence are suggestive of celadonite, but the refractive indices are considerably lower than those recorded by Hendricks and Ross (1941, p. 687) and Winchell (1933, p. 436) for this mineral. Microchemical tests indicated some K_2O, but whether it is present in sufficient amount to warrant classification as celadonite is by no means clear; certainly in some of the analyses quoted by Hendricks and Ross (*loc. cit.* p. 697) K_2O is moderately low. In one case, however (P. 4888), greenish-brown biotite was observed filling the centre of one vesicle and merging into the green lining, but it is not thought that this indicates that biotite has developed from the green mineral. Therefore, until more work can be carried out on this problem, the material will be referred to as the amygdule mineral.

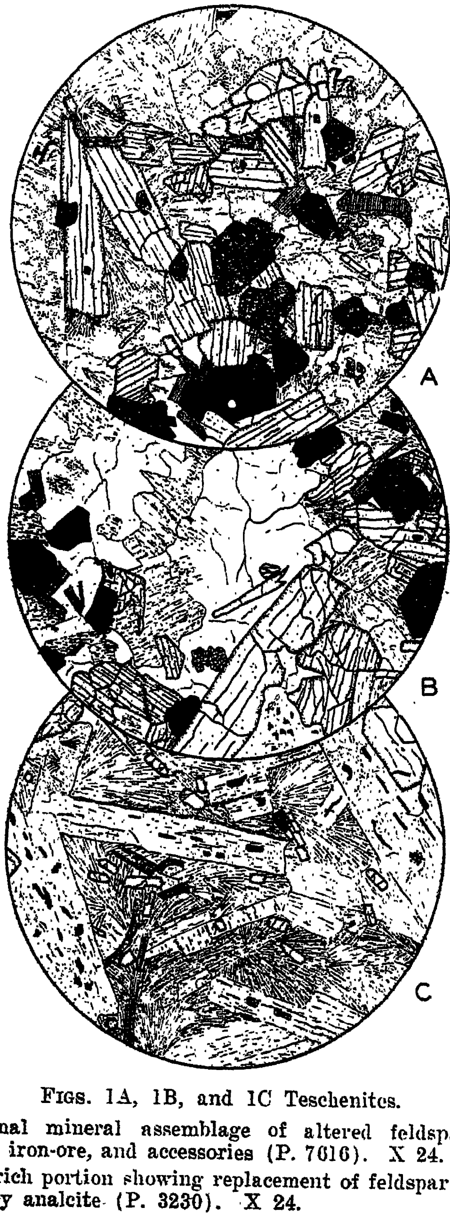
PETROGRAPHY.

The igneous rocks of the Brocken Range–Ngahape area, as have been described by Brown (1943), occur in three distinct localities, and the rocks themselves are capable of subdivision into three petrological groups—viz.:

A. Teschenites (Brocken Range).
B. Altered olivine dolerites and dolerites with spilitic and teschenitic affinities (Kaiwhata River).
C. Variolites (Ngahape).

A. *Teschenites* (text fig. 1; plate 39, fig. 1). In the hand-specimen these rocks are melanocratic, fairly coarse, equigranular rocks, weathering to a reddish-brown soil. Microscopically the rock has a hypidiomorphic granular structure, though in parts where feldspar is completely replaced by zeolite a pseudo-porphyritic texture is developed. Plagioclase occurs in lath-like and tabular crystals up to 2.0 mm. in length. Twinning on Carlsbad, albite and pericline laws is general and zoning is most pronounced. The composition ranges from An_{67} in the interior to An_{45} in the most acid peripheral zones. The feldspar is heavily loaded with inclusions of apatite, biotite, and iron ore, and usually has a blotched appearance due to extensive replacement by thomsonite and minor natrolite. The pyroxene, a diopsidic type moderately rich in TiO_2, has crystallised in idiomorphic to sub-idiomorphic grains averaging 0.75–1.0 mm. in diameter. In thick grains the colour is pale pink, with the pleochroism faint but distinct. In the material separated for analysis the optical axial angle is 50° – 54°, but in the large crystals in the thin slices strong zoning is developed, sometimes with poor hour-glass structure, consequently the angle 2V is not constant. In the narrow outer zones the angle was found to vary from 42° – 46°, while the refractive index in one case rose from 1.715 to approximately 1.725. This general decrease in the optic axial angle and increase in refractive index in the outer zones of phenocrystic pyroxenes has been noted by Barth (1931), Kuno (1936)

and in New Zealand by Benson and Turner (1939, p. 68). These workers interpret these data as showing an increase in the clinoferrosilite molecule and concomitant decrease in the diopside molecule as crystallization advanced; that is, an enrichment of the later differentiates of the magma in iron.



FIGS. 1A, 1B, and 1C Teschenites.

A. The normal mineral assemblage of altered feldspar, zeolites, pyroxene, iron-ore, and accessories (P. 7616). X 24.

B. Analcite-rich portion showing replacement of feldspar and fibrous zeolites by analcite (P. 3230). X 24.

C. Insertal areas of fibrous zeolites due to crystallization of late magmatic liquids (P.3231). X 24.

Irregularly shaped platy aggregates of bowlingite were noted. Although in some cases it appears to be partially rimming augite, more often the aggregates suggest the shape of former olivine crystals, after which it is possibly pseudomorphous. Occasionally it penetrates along the cleavage planes of the zeolite-flecked plagioclase crystals (P. 3231). The colour varies from a bluish green to bright green, and pleochroism is fairly strong according to the scheme: $X =$ yellow, $Y = Z =$ deep olive green, with absorption $X < Y = Z$. Some minor grains of ferriferous epidote are often associated with bowlingite.

Sheaf-like radiating aggregates of thomsonite are abundantly developed throughout these rocks in the interspaces between the clinopyroxene and plagioclase, and as irregular patches within the feldspar itself (text Figs. 1A and B). Minor natrolite is closely associated with the thomsonite in the aggregates.

Intensely pleochroic scraps of biotite occur, particularly in P. 3231, closely associated with grains of iron ore, although sometimes appearing to form a partial rim to clinopyroxene (text Fig. 1A). Much of the mica is altered to a pale green negative chlorite. The biotite appears to have crystallised at a period intermediate between the crystallisation of pyroxene and crystallisation of the zeolites. Some sphene, possibly a by-product of the biotite → chlorite reaction, was noted.

Analcime ($n = 1.482$) is most plentiful in some thin slices, and it is usually filled with the dust-like inclusions seen in the plagioclase; it has replaced much of the latter material. No thomsonite is visible in these "pools" of analcite, although the fibrous zeolite is abundant as flecks in the unaltered plagioclase. It is suggested that this points to the possible replacement of thomsonite as well as the feldspar by analcime. It might be contended, however, that on account of the absence of fibrous zeolite within areas of completely analcitized plagioclase, the crystallisation of the thomsonite and natrolite post-dated that of analcime. There is, though, no evidence in support of this contention. Apatite, in needles and stout hexagonal prisms up to 1.0 mm. in length, is a constant and abundant accessory, and it appears to be concentrated to some extent in the intersertal areas occupied mainly by zeolites and biotite (text Fig. 1C). The hexagonal prisms appear to be free from inclusions.

Ilmenite-haematite solid solution is abundant in idiomorphic to sub-idiomorphic grains, usually octahedra, averaging 0.3 mm. in diameter, but occasional highly irregular grains, 2.0 mm. in diameter, are met with. Partial rimming with biotite is common, and ovoid areas of biotite, augite, bowlingite and zeolites occur as inclusions.

These rocks are fairly typical of melanocratic teschenites, and their chemical composition is similar to that of the original teschenite from Silesia, although the New Zealand rocks lack barkevikite (compare analyses A and B, Table 4). The percentage of TiO_2 is rather unusually high in the rock from Red Hill, and this is due to the important amount of iron ore present.

TABLE 4.—ANALYSES OF TESCHENITES.

	A.	B.	C.	D.
SiO_2	41.06	41.42	45.68	45.52
Al_2O_3	12.75	15.07	12.44	16.08
Fe_2O_3	2.24	7.93	3.25	4.18
FeO	11.48	—	6.95	6.37
MgO	6.53	4.82	8.56	4.85
CaO	9.55	10.16	10.43	8.34
Na_2O	4.22	4.00	3.53	4.63
K_2O	0.80	1.98	0.80	2.09
H_2O + ...	3.78	2.73	2.97	4.92
H_2O — ..	0.40	0.27	1.94	
CO_2	trace	—	0.15	—
TiO_2	6.35	3.14	2.56	2.07
P_2O_5	0.39	1.57	0.52	—
ZrO_2	nt.fd.	—	nt.fd.	—
S	0.09	0.37	0.10	—
MnO	0.12	0.20	0.29	—
NiO	0.05	—	0.03	—
Cr_2O_3	nt.fd.	—	0.04	—
V_2O_3	0.08	—	nt.dt.	—
BaO	0.03	—	nt.fd.	—
SrO	0.03	nt.fd.	present	—
Cl	nt.fd.	0.05	nt.dt.	—
F	0.04	0.10	nt.dt.	—
	99.99	93.81*	100.24	100.00†

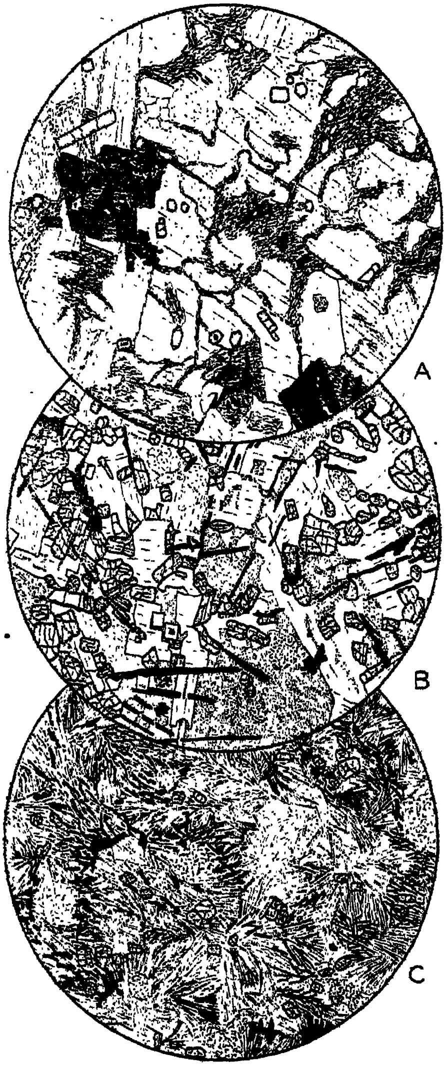
A. Teschenite, P.7616, from Red Hill, head of Upokongaruru Stream, west side of Brocken Range, Rewa S.D. Anal.: F. T. Seelye.
B. Teschenite, Paskau, 25 km. west of Teschen, Mahren, Silesia. * Total includes FeS 0.06, FeS_2 0.04. (Johannsen, 1938, p. 229). Johannsen's total is incorrect; possibly FeO was omitted.
C. Teschenite, Warman's Point, P.6458, Mangapai, Ruakaka S.D. Anal.: F. T. Seelye.
D. Teschenite, average of twelve analyses, quoted from R. A. Daly, 1933, p. 22. † Total includes 0.95% of minor constituents.

In many ways the Red Hill teschenites are comparable with rocks described by Benson (1942) from Eastern Otago, and especially the rock investigated by Bartrum (1925, p. 10) and Ferrar (1934, pp. 55–56) from Mangapai Estuary, Whangarei Harbour (Analysis C, Table 4). However, the Red Hill teschenites differ from these in that there is a complete absence of aegirine–augite mantling the titan–augite, or occurring as individual crystals in the mesostasis; a further distinction is the apparent absence of fibrous zeolites from the Mangapai rock. The Mangapai and Red Hill rocks appear to be remarkably low in K_2O as compared with the average of twelve teschenites. (Analysis D, Table 4), and both rocks show development of leucocratic, possibly late magmatic, areas (c.f. Text Fig. 1C and Plate 39, Fig. 2).

B. *Dolerites* (text Figs. 2A and B).

Altered olivine dolerites: Macroscopically these rocks, represented by only two specimens, are dense, dark and fine-grained. In thin section they are seen to be somewhat altered, but holocrystalline with a granulitic structure. The plagioclase occurs in

lath-like and tabular crystals, often up to 2.5 mm. in length, showing single and multiple twinning. Zoning is quite pronounced, with the composition determined by universal stage methods, varying from An_{53}–An_{58} centrally to An_{45} in some narrow peripheral zones. Inclusions of augite and fine-grained groundmass are common and are frequently concentrated at the centre of the plagioclase crystals.



FIGS. 2A, 2B, 2C.

A. Quartz-albite dolerite with much bowlingite (P. 7601). X 24.

B. Altered olivine dolerite with interstitial patches of finely crystalline, almost variolitic material (P.7602). X 24.

C. Variolite (P.7608). X 24.

Clinopyroxene appears to be restricted to one generation, and occurs in granules averaging 0.3–0.4 mm. It is a pale purple or pink titan-augite with 2V = 51°–53° and $Z \wedge c$ = 43°. According to Wager and Deer's diagram (1939, p. 80), the composition of the pyroxene should be about $CaSiO_3$ 35, $MgSiO_3$ 45, and $FeSiO_3$ 20. Bowlingite occurs in fibrous aggregates that appear to simulate the outlines of olivine crystals, but whether all the bowlingite is pseudomorphous after original olivine is by no means certain. The colour is pale yellow for α and deep yellow or greenish-brown for γ. The borders of the bowlingite aggregates are often outlined with brown granular limonite, possibly due to decomposition of the mineral itself. This material is referred to bowlingite rather than to iddingsite on account of the pleochroism and refractive index. Ross and Shannon (1926, pp. 13-14) show that the refractive index for α is 1.70 or higher and that a ruby-red tint is common for the γ vibration direction in iddingsite. However, the refractive index of the bowlingite is lower than 1.70 and the characteristic ruby-red tint is lacking.

Ilmenite is an important accessory constituent occurring in rather ragged bars up to 0.6 mm. in length, in ragged grains and in dendritic forms. The bars or rods are very often parallel among themselves in a fashion similar to that described by Campbell, Day and Stenhouse (1932, p. 353) for iron-ore in segregation veins in some teschenites (text Fig. 2B). Needles of apatite and some calcite are present.

Throughout the rock are numerous interstital patches of finely crystalline material that appears to have been formed from a late, more acid residual liquid (text Fig. 2B). They consist of augite, iron-ore, and bowlingite, set in a plexus of slender laths of plagioclase; the feldspar crystals are too fine for precise determination, but they usually show multiple twinning. In the feldspar laths inclusions of extremely narrow, longitudinal zones of cryptocrystalline material clouded with magnetite dust occur.

Albite dolerites: In the hand-specimen albite dolerites are fairly coarse-grained, crumbling rocks, sometimes with long laths of feldspar up to 25 mm. in length, and sometimes large black crystals of pyroxene. In colour they vary from grey or buff to a glauconite-green.

Microscopically they are all considerably altered. They are holocrystalline and often exhibit an intersertal or sub-ophitic texture with coarse idiomorphic crystals of plagioclase that are generally dusty in appearance, though the margins may be clear. The mesostasis between these crystals is varied and may consist of a mosaic of feldspar and quartz, or feldspar, quartz, and bowlingite; the quartz and feldspar do not show any micrographic relationship as has been described by Benson (1915, p. 142), although the association is an intimate one.

The feldspar is in excess of pyroxene and occurs in sub-idiomorphic plate-like crystals and broad laths, universally twinned on Carlsbad, albite and pericline laws. The plagioclase crystals are slightly zoned and in some cases (P. 7615) have been affected by shearing with consequent cracking, bending or granulation. Inclusions

are often dense and are arranged centrally, leaving the periphery quite clear. The inclusions noted were clinozoisite, iron-poor epidote, and apatite, with a dusting of sericite and kaolin in most cases. Bowlingite has intimately penetrated the cracks and cleavage planes of plagioclase crystals.

Augite occurs in two rocks (P. 7607, 7615) but is an important constituent of only one (P. 7607). It occurs in large, very pale pink grains up to 2.5 mm. in diameter, sometimes sharply idiomorphic, but with very faint pleochroism. The clinopyroxene is usually considerably altered to leucoxenized ilmenite and chloritic or bowlingitic alteration products. In places a tendency towards an ophitic relationship with feldspar is to be seen. Quartz occurs in small interstitial water-clear allotriomorphic grains, although a few large grains up to 1.0 mm. in diameter occur in one of the rocks (P. 7601, text Fig. 2A), while in P. 7606 rare clear zones of quartz were noticed surrounding dusty, somewhat altered acid oligoclase.

One of the rocks shows transition to the micro-teschenites (Hatch and Wells, 1937, p. 226) with the development of plentiful analcime. This constituent extensively replaces the plagioclase, for fragments of feldspar occur floating about in analcime, while in other places the zeolite is crossed by lines of bowlingite, the latter mineral formerly occurring as a filling to cleavage cracks of the replaced feldspar.

Bowlingite is a common constituent and has possibly been derived from olivine as well as from the clinopyroxene, the latter often occurs as relict granules in pools of bowlingite. It is usually interstitial and, sometimes microspherulitic in habit. It is uniaxial negative and distinctly pleochroic with X = colourless to pale yellow and Y = Z = green to greenish-brown.

Acicular hexagonal prisms of apatite, up to 2.5 mm. in length in some cases (P. 7607), is a common accessory constituent. In one example (P. 7601) the prisms have a central, narrow zone of inclusions parallel to the C-axis. They are pale yellow in colour and have a refractive index slightly less than that of the apatite. It was not possible to identity the material, but it is suggested that it is an hydroxyapatite surrounded by normal apatite.

Iron-ore occurs in bars and skeletal crystals and in subidiomorphic grains; knee-shaped twins have been noted (P. 7601). A positive titanium reaction was generally obtained on the separated ore, but the paramagnetic properties were stronger in some grains than in others; probably titaniferous magnetite and ilmenite are both present. Leucoxene was noted in some cases closely associated with the ore. Minor calcite was observed in the three rocks of this group, although no CO_2 is recorded in the analysis of one rock (Table 5, analysis C.).

C. *Variolites* (text Fig. 2C.).

This group of rocks is represented by a number of specimens (P. 4886-4893, P. 7608). In the hand specimen the variolites are dark green to black massive fine-grained rocks with amygdules filled with calcite, and patches of black, shining micaceous minerals are very conspicuous in some specimens.

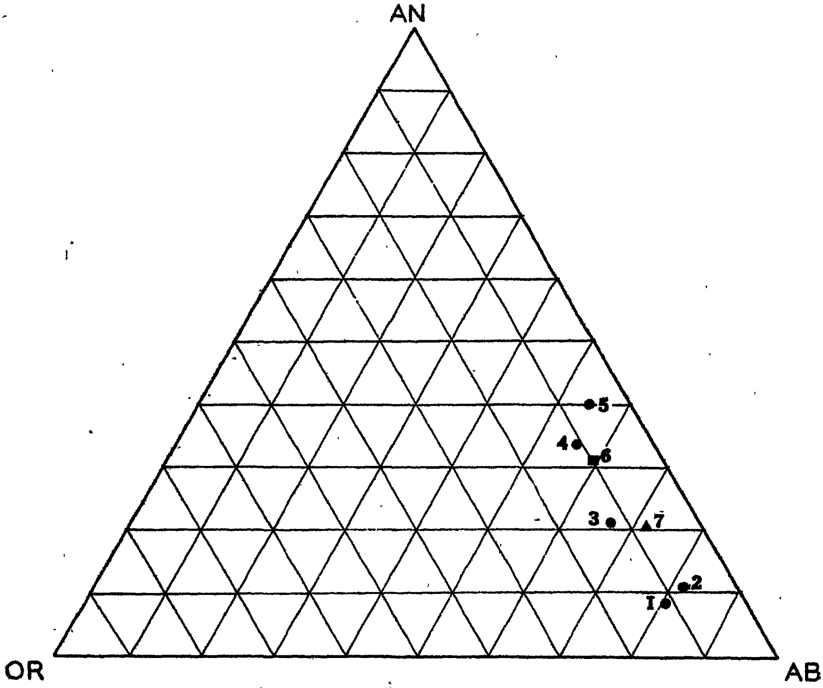


FIG. 3.

Molecular percentages of normative feldspars of Brocken-Kaiwhata area rocks, compared with average spilite feldspar. 1 = anal. B, 2 = anal. E, 3 = anal. C, 4 = anal. A, 5 = anal. G (all of Table 5); 6 = Red Hill teschenite (normative nepheline calculated as albite); 7 = average spilite.

Microscopically the rocks consist of radiating aggregates of acicular crystals of feldspar, bars and dendritic forms of leucoxenized ilmenite and slender blade-like crystals and granules of augite. There is an approach to the cervicorn structure so characteristically seen in certain of the cone-sheets of Mull, Thomas and Bailey, 1924, p. 303) and Ardnamurchan (Thomas, 1930, p. 171). These radiating aggregates do not exceed 0.75 mm. in diameter. Occasional minute tabular crystals of plagioclase occur with a central aggregate of inclusions and a clear peripheral zone. Owing to the very fine grain-size it is not possible to determine the exact composition of the plagioclase, except that the α refractive index direction is slightly greater than that of Canada balsam. The composition is therefore about acid to medium andesine, and this is supported by the feldspar of the norm calculation (Table 5, analysis G.). The rounded grains of pale purple augite average 0.75 mm. in diameter; occasional glomero-porphyritic groups of grains were noted.

The amygdule mineral previously described in the section on mineralogy is fairly plentiful. Under low power it has a gel-like, glauconitic appearance, but with greater magnification, it is observed to be built up of aggregates of minute, positively elongated flakes. In one amygdule lined with the green mineral, a central zone is composed entirely of greenish-brown biotite in flakes averaging 0.15 –

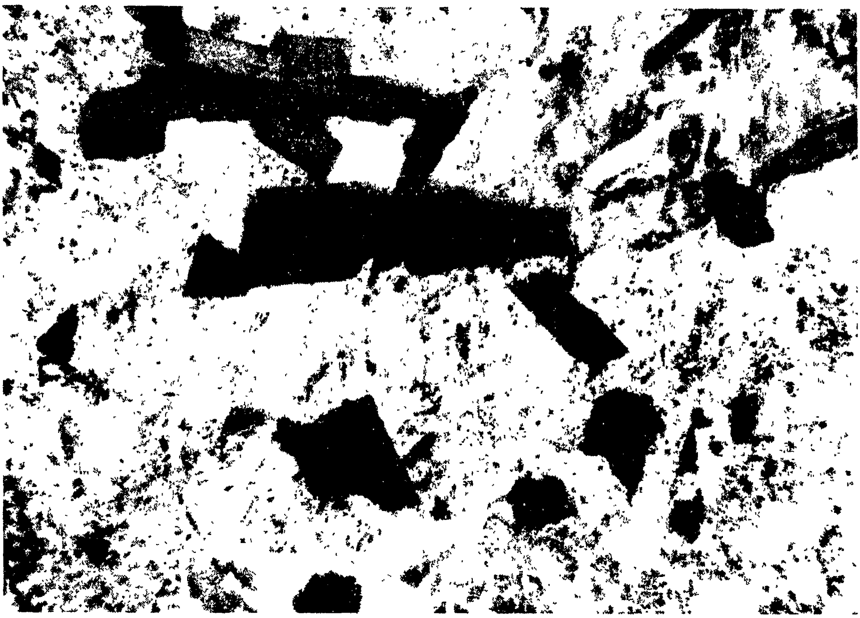


Fig. 1 (Upper). The normal association in Red Hill teschenite (P.3230). X 70.

Fig. 2 (Lower). Leucocratic phase of the Mangapai teschenite (P.6458), showing partially analcitized plagioclase and plentiful biotite and apatite. X 70.

To face page 364]

0.2 mm. in length. These flakes have a sheaf-like or radiating arrangement, and owing to the intense pleochroism good black crosses can be observed. Calcite is also plentiful in most of these rocks as a filling in vesicles, and it may occur with or without the green constituent. In some vesicles patches and ragged wisps of the green mineral occur "floating" in calcite, and this relationship suggests that the calcite is of later origin and that it has replaced the amygdule mineral. Occasionally a pale yellow glassy or cryptocrystalline material accompaies the amygdule mineral. It has not been possible to identify this, but under a high power magnification numerous radiating bundles of needle-like colourless crystals were noted; these needles were negatively elongated. This cryptocrystalline material might possibly be a zeolitic gel.

PETROGENESIS.

On Table 5 the analysis of the dolerites and variolites are compared with similar rocks. The analysis of the albite-dolerites (B and C) are like that of a dolerite (D) described by Benson (1915) and associated in the field with spilites, while the albite dolerite (E) is very similar in composition to an albitic quartz. dolerite (F) also described by Benson (1915). The variolite (G), on the other hand, can be compared chemically with the more normal basalt or diabase (H). However, the features that are of the greatest interest in all of these rocks from the Brocken-Kaiwhata area are: (1) poverty in K_2O; (2) richness in Na_2O; and (3) the fairly low figure for Al_2O_3. These characters at once point to a possible connection with the rocks of the so-called spilitic suite of spilites and keratophyres. In the case of the three albitic dolerites (Table 5, B, C, E) the normative plagioclase is Ab_{91}, Ab_{76} and Ab_{88} respectively, but these figures do not completely support the evidence obtained from the feldspar determination by universal stage methods. This work showed that the plagioclase, though zoned, was never more basic than acid oligoclase ($Ab_{88}An_{12}$), thus the excess CaO must be present in the clinopyroxene. Also some clinozoisite or epidote is present, and the Al_2O_3 and CaO required for these minerals in the mode would be calculated as anorthite in the norm. The relative poverty in K_2O pointed out by Sundius (1930, p. 9) as a special characteristic of the spilitic series is, for the Brocken-Kaiwhata rocks, clearly shown in the ternary diagram, Or–Ab–An (text fig. 3). With regard to the Na_2O content, B. and E. are more sodic and C. very slightly less sodic than the averaged normative feldspar (point 7) of a number of spilites. The feldspars of the altered dolerites and variolites, A. and G. respectively, are on the other hand richer in CaO, though still poor in potash. They lie on the sodic side of the diabase group that Sundius (1930, p. 9) believes might possibly be separated from the field of spilitic feldspars, although Gilluly (1935A, p. 249) points out that there appears to be a complete gradation from spilitic to normal subalkaline rocks.

From the Kaiwhata sill itself, altered olivine (?) dolerites, quartz-albite dolerites, albite dolerites, and analcime-bearing albite dolerites have been described, and this association suggests the possibility that after the magma was injected into the sill slight gravitative differentiation took place. Unfortunately, this was not realised until examination of the rocks was under way in the laboratory, and

then it was not possible to return to the field to verify the truth or otherwise of this hypothesis. The writer submits that all the dolerites, teschenites, and variolitic pillow lavas are closely associated magmatically and that they were emplaced about the same time. One cannot but be impressed with the chemical similarity of the teschenite, dolerite and variolite, and there would seem little doubt of their derivation from a single magma. It is suggested that the teschenite represents a differentiate of a fairly normal basaltic magma in place, somewhat similar to that described by Campbell, Day and Stenhouse (1934) in the case of the Braefoot Outer Sill in Fifeshire. With the intrusion of the teschenite at depth, a portion of the doleritic material was injected into the now westerly dipping Raukumara sediments to form the Kaiwhata sill. Slight differentiation of the doleritic magma in this sill may have occurred causing an enrichment of the residual magma in soda and water, resulting in crystallization of analcime and albite. At the same time as the Kaiwhata sill was emplaced, a portion of the magma was poured out on to the wet sediments of the Upper Cretaceous sea floor to form the variolitic pillow-lavas.

In the teschenite itself the residual liquids after crystallization of the labradorite and diopsidic augite, appear to have been enriched in soda and water, resulting in the late crystallization of fibrous zeolites, followed by analcime, which has partially replaced plagioclase and earlier zeolites. This late crystallization of analcime after the other zeolites does not appear to be common, although Gilluly (1927, p. 204) states that thomsonite and analcime have crystallized simultaneously, followed by natrolite, in a diabase from Utah. Similarly in the Watchung basalts, Fenner (1911) has shown that one zeolite may crystallize at the expense of another, due to falling temperature of late-magmatic solutions. In the Red Hill teschenite both natrolite and thomsonite appear to have crystallized at the same time, and it is believed, chiefly on account of relative abundance and relationship to other minerals that they are primary magmatic constituents and are not the result of secondary alteration of plagioclase.

In the variolites an interesting association of minerals has been observed filling the vesicles, viz., the green "celadonitic" mineral, calcite, biotite, and some cryptocrystalline material, referred to before as a zeolitic gel. It is the writer's opinion that the "celadonitic" amygdule mineral has crystallized from later magmatic ferruginous gels or solutions, and this supposition is in line with the general theory put forward by Fenner (1929, p. 245) that there appears to be a concentration of iron and alkalies in liquids given off by basic magmas; following Hendricks and Ross (1941, p. 705) the mineral may be termed a metacolloid. Furthermore, Jolliffe (1935, p. 422) comes to the conclusion that the green iron-rich mineral, greenalite, of the Biwabik formation of Minnesota, owes its origin to ferrous solutions of direct igneous origin; possibly a reducing environment would be necessary. As stated previously, brown rims to the green amygdule mineral are common, and these are possibly due to (1) oxidation of the ferrous iron in the green mineral,; or (2) the result of difference in composition of the gel, perhaps higher Fe_2O_3, at the time of deposition.

The rare occurrence of greenish biotite in association with, but of later origin than, the green mineral, is interesting, and appears

to indicate that the very latest of the solutions to crystallize were rich in potash as well as in ferrous iron (cf. Fenner, 1929, p. 245).

The question of soda-metasomatism versus primary magmatic crystallization of albite in spilites and allied rocks has been discussed by many writers and summarised by Gilluly (1935A and B), who contends that ophitic structure is no sure criterion of primary origin of the albite in the rocks concerned. This seems to be a very good clue indeed, for it is difficult to understand how albite could crystallize on ophitic relationship with augite when the physical chemistry of the problem is considered. However, attention is now drawn to the following characters shown by the Brocken rocks:—

(1) No trace of the mottling of feldspars such as described by Gilluly (1935A, 229) was observed in the Brocken rocks, and in this respect they are similar to the sodic plagioclases in the rocks described by Bartrum (1936), although the feldspars in the Brocken rocks do not have an unaltered appearance.

(2) No adinolization appears to have occurred, although it must be admitted that a specific search for this feature was not carried out. However, thin sections of near-by greywackes show no signs of enrichment in albite.

(3) There is not any sign of the form that the expelled anorthite molecule would have taken if soda metasomatism has taken place.

(4) The pyroxene, when present, in the sodic rocks of the Brocken-Kaiwhata area is considerably altered, and also occurs as remnants set in a bowlingitic matrix. But little or no epidote, clinozoisite, or calcite occurs associated with the bowlingitic pseudomorphs of the pyroxene.

(5) Analcime is present in some of the dolerites, while analcime and fibrous zeolites are plentifully developed in the teschenites.

No positive conclusion as to the origin of albite in the Brocken rocks is warranted on the above evidence.

At this stage in the discussion it may be appropriate to mention the lack of spilitic characters in the majority of the post-Jurassic demonstrably submarine pillow-lavas of New Zealand. As instances may be cited the normal basaltic pillow lavas of the extreme north-west corner of the North Island of New Zealand (Bartrum and Turner, 1928), of the coastal area west of Auckland City (Bartrum, 1930) of the Oxford District of Canterbury (Speight, 1928), of the Oamaru District, north Otago (Park, 1918), and of Matira Creek in the Huntly-Kawhia area (Henderson and Grange, 1926).

Finally it should be noted that other doleritic rocks are known in the Wairarapa area, but these await investigation. It will be sufficient to say that analcime-bearing types have been identified by the writer among specimens from the Eketahuna Subdivision at present being investigated by Mr. M. Ongley, while dykes occur in Cretaceous rocks near Flat Point, south of the mouth of the Kaiwhata River. These latter rocks have been quaintly described by Sollas (1906, pp. 153–154) as hypersthene andesites, but both are altered augite dolerites, some with variolitic structure. Similar igneous rocks from the Tinui area in Wellington Province remain to be described.

TABLE 5.—ANALYSES OF DOLERITES AND VARIOLITES.

	A.	B.	C.	D.	E.	F.	G.	H.
SiO_2 ..	44.79	47.20	49.18	48.35	53.37	54.88	44.45	44.87
Al_2O_3 ..	11.45	13.24	14.46	14.12	15.22	12.62	12.78	13.60
Fe_2O_3 ..	0.65	5.37	5.29	4.87	4.23	3.02	4.98	5.65
FeO ..	9.06	7.83	7.04	10.27	4.89	7.11	4.91	5.68
MgO .	5.03	7.12	4.05	4.78	2.22	3.73	6.82	9.39
CaO ..	12.29	3.08	5.84	6.71	5.43	4.16	9.53	11.05
Na_2O ..	2.93	3.93	4.96	4.63	6.88	6.01	3.13	3.41
K_2O ..	0.75	0.78	1.29	0.38	0.91	1.10	0.44	0.45
H_2O +	0.98	4.76	2.67	2.00	1.97	1.76	1.98	2.05
H_2O —	1.58	2.05	0.90	0.30	0.90	0.23	5.36	1.48
CO_2 ..	6.61	0.34	nt.fd.	nil.	1.38	trace.	1.40	—
TiO_2 ..	2.91	2.57	3.22	2.84	1.82	3.63	3.17	2.13
P_2O_5 ..	0.73	1.49	0.88	0.35	0.70	0.44	0.72	—
ZrO_2 ..	nt.fd.	nt.fd.	nt.fd.	—	nt.fd.	—	nt.fd.	—
S. ..	0.09	0.03	0.07	0.22 (FeS)	0.02	0.71 (FeS)	0.07	—
MnO ..	0.14	0.14	0.19	0.18	0.10	0.25	0.13	—
NiO ..	0.03	nt.fd.	nt.fd.	—	nt.fd.	0.05	0.03	—
Cr_2O_3 ..	0.08	nt.fd.	nt.fd.	—	nt.fd.	nt.fd.	0.04	—
V_2O_3 ..	0.02	0.02	0.03	—	0.01	—	0.03	—
BaO ..	0.03	0.11	0.08	0.10	0.05	nt.fd.	0.02	—
SrO ..	0.05	0.01	0.06	—	0.025	—	0.10	—
Cl. ..	nt.fd.	trace ?	trace ?	—	trace ?	—	trace ?	—
F. ..	0.065	0.11	0.068	—	0.08	—	0.084	—
	100.26	100.18	100.28	100.10	100.21	99.70	100.17	99.76
O. for F.	—	0.05	0.03	—	0.03	—	0.04	—
Total ..	100.26	100.13	100.25	100.10	100.18	99.70	100.13	99.76

NORMS.

		A.	B.	C.	D.	G.	H.
Q.		5.82	6.58	—	0.68	2.85	—
Or. . ..		4.45	4.62	7.63	5.39	2.64	2.78
Ab. .. .		24.80	33.24	41.94	58.20	26.48	19.39
An.		14.46	3.40	13.41	7.96	19.53	20.29
Ne.		—	—	—	—	—	5.11
C.		0.51	4.69	—	—	—	—
di	$CaSiO_3$	—	—	4.09	2.38	6.03	27.26
	$MgSiO_3$	—	—	2.77	1.51	5.21	
	$FeSiO_3$	—	—	1.00	0.73	—	
hy	$MgSiO_3$	12.53	17.73	6.81	4.03	11.78	—
	$FeSiO_3$	11.65	5.97	2.48	1.94	—	—
ol	Mg_2SiO_4	—	—	0.36	—	—	9.08
	Fe_2SiO_4	—	—	0.14	—	—	
	mt. ..	0.79	7.78	7.53	6.14	7.07	8.35
	il. ..	5.52	4.89	6.12	3.46	6.03	1.10
	hm. ..	—	—	—	—	0.02	—
	Ap. ..	1.71	3.53	2.09	1.65	1.71	—
	pr. ..	0.17	—	0.13	—	0.13	—
	(cc) ..	(15.02)	(0.77)	—	(3.14)	(3.18)	—
Normative plagioclase		Ab_{63}	Ab_{91}	Ab_{76}	Ab_{88}	Ab_{58}	

A. Altered olivine dolerite. P. 7602. From sill crossing Kaiwhata Stream 20chs. upstream from Ngahape. Rewa S.D. Analyst: F. T. Seelye.
B. Quartz-albite dolerite. P. 7601. Locality as for P. 7602. Analyst: F. T. Seelye.
C. Albite dolerite. P. 7607. Locality as for P. 7602. Analyst: F. T. Seelye.
D. Dolerite, Munro's Creek, Bowling Alley Point, Nundle District, N.S.W. (Benson, 1915, p. 139, analysis 1002).
E. Albite dolerite, P. 7615. Locality as for P. 7602. Analyst: F. T. Seelye.
F. Quartz dolerite, Hanging Rock, Nundle District, N.S.W. (Benson, 1915, p. 139, analysis 145).
G. Variolite. P. 7608, Ngahape "Bluff," opposite junction of Waipapa Creek and Kaiwhata Stream. Analyst: F. T. Seelye.
H. Basalt. Wiebel, near Steinbach, Giessen, Hesse. Analyst: A. Streng (Washington, 1917, p. 632, analysis 10). The total recorded in Washington

ACKNOWLEDGMENT.

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Descriptions of Two New Species of Lepidoptera.

BY W. GEORGE HOWES.

[*Read before the Otago Institute, October 13, 1942; received by the Editor, November 23, 1942; issued separately, March, 1943.*]

Ichneutica homerica n. sp. Fig. 1.

Male.

Head grey. Thorax grey with the patagia outlined in black.

Thorax stout, being 9 mm. broad by 6 mm. deep.

Forelegs dark brown with ochreous annulations at joints.

Abdomen grey-brown with darker lines across each segment.

Wing expanse 47 mm. Ground colour of wing dull greyish brown.

Markings distinct in grey or black.

Greyish patch at base—basal line black.

First line grey distinctly edged with black. Space between first line and basal line shows grey patches outlined in black. Second line strongly indented, grey. Space between this and first line darker than the rest of the wing and including an indented darker line. Subterminal area clouded with darker patches.

Reniform and orbicular appear as clear, ochreous patches, not very distinct in their outline. The reniform is margined outwardly with a patch of ochreous grey.

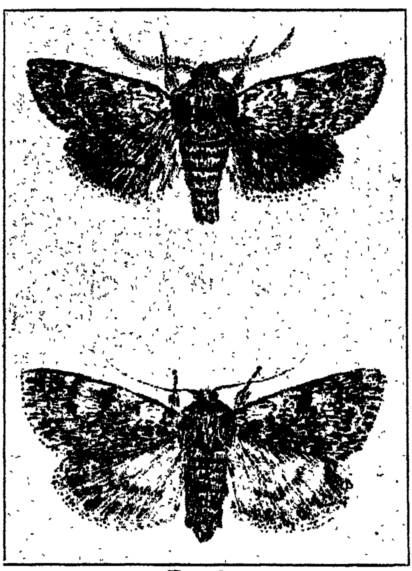

FIG. 1.

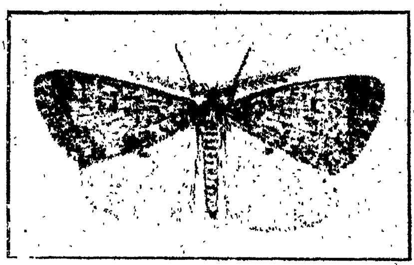

FIG. 2.

Veins are outlined in black with grey-brown points at base of cilia. Cilia black.

In perfect specimens a faint bluish irridescence enriches the forewings.

Hindwings grey with a faint cloudy median line. Lunule faint. Cilia grey with a brownish tint at base.

Female.

Wing expanse 51 mm. Thorax grey and not showing so distinctly the darker lines on the patagia as in the male.

General colour lighter than that of male.

Cilia of forewings barred black and grey.

The underwings being lighter than those of male the median line shows more distinctly.

Cilia light grey with two distinct darker lines.

This species was fairly commonly attracted to light at Homer. Two specimens seen on different days flying over the open ground in the daytime.

The general colour of this fine moth is very similar to the colouration of the rock formations in the district.

There is hardly any variation, but a number of specimens taken are slightly smaller than the types selected.

Plentiful from 17th December until 4th January, after which only an odd specimen was seen. Types and co-types in author's collection.

Selidosema berylia n. sp. Fig. 2.

Head and thorax dark brown, abdomen ochreous.

Antennal pectinations long—dark brown.

Wing expanse 47 mm.

Forewings dull coppery brown with markings indistinct, being but slightly darker than the general surface.

Discal spot elongate and distinct.

The basal line is very small.

First line shows plainly on costa, is faintly indicated across wing and then again distinct on dorsum.

Second line also faint in centre of wing with a sharp angulation outwards just above dorsum.

Subterminal line faintly indicated except near apex, where three or four dots form a dark area. One or two of these dark marks have white dots on their terminal side.

All these lines are faint, being but slightly darker than the general surface of the wings, and they vary in intensity slightly in different specimens.

The veins are lightly outlined in darker ending in a terminal series of black dots.

Cilia brownish grey.

Underwings grey-white with minute dots of darker grey.

Cilia ochreous-white. Discal dot small but plainly indicated.

Attracted to light at Homer. Two specimens taken early in January, while from January to May Mrs J. Sutherland kindly collected for me about 70 specimens—all at light. This large number was secured in the hopes of getting the female, but none appeared. There was very little variation except that the depth of colouring was lighter in some specimens. The size was fairly constant, varying from 42 mm. to 47 mm. The female may prove to be apterous. Male types in author's collection.

New Records of Collembola from New Zealand, with Descriptions of New Genera and Species.

Part I. *Collembola.* Arthropleona.

By J. T. SALMON, M.Sc., Entomologist, Dominion Museum.

[*Read before the Wellington Branch, September 23, 1942; received by the Editor, September 28, 1942; issued separately, March, 1943.*]

Twelve new species and two new genera are added to the New Zealand Collembolan fauna by this paper, which also contains notes on the distribution of a number of known species. In many cases these notes are of particular interest, as they extend the distribution of species previously known only from the South Island to the North Island as well.

Family ACHORUTIDAE.

Sub-family ACHORUTINAE.

Genus TRIACANTHELLA Schaeffer.

Two further species of this genus have now been discovered in New Zealand, bringing the total number of species of *Triacanthella* known from the New Zealand region up to six. These may be separated according to the following key:—

1.	Ocelli eight on each side, of which none are rudimentary. ..	2
	Ocelli eight on each side, of which two are reduced. ..	4
2.	Claw without any teeth, clothing of strongly serrated setae. ..	*T. setacea* Salmon.
	Claw with inner and outer teeth. ..	3
3.	Clothing of simple setae; postantennal organ with four lobes, dens with apical scale-like lobe. ..	*T. rubra* Salmon.
	Some of the setae serrated, postantennal organ with five lobes, dens without apical scale-like lobe. ..	*T. purpurea* sp. nov.
4.	Empodial appendage absent, postantennal organ with four lobes. ..	*T. rosea* Wahlgren.
	Empodial appendage present but rudimentary. ..	5
5.	Claw without any inner teeth, a single distinctly clavate tenent hair to each foot, mucro with apical lobe and dens with apical scale-like lobe. ..	*T. alba* Carpenter.
	Claw with two inner teeth, no clavate tenent hairs, dens without apical scale-like lobe. ..	*T. terrasilvaticas* sp. nov.

Triacanthella setacea Salmon, 1941.

This species has now been found in leaf mould at Buller's Bush, Levin, by the author, thus extending its distribution to include the North Island as well as the South Island.

Triacanthella purpurea sp. nov. Pl. 40, figs. 1-5.

Colour: In life dark-reddish-violet to purple or dark-bluish violet, fading to light- or dark-red in spirit.

Clothing: Numerous long and short setae; the long setae particularly around the posterior portion of the abdomen about 3-4 times as long as the short setae. Many of the long setae are coarsely and irregularly serrated.

Body: Length up to 1.5 mm. Antennae shorter than the head. Ant. IV with three (sometimes four) exsertile knobs at the tip. On the dorso-lateral anterior extremity of Ant. III there is a sensory organ, consisting of two short curved sense rods, each arising from a shallow pit. Eight large equal ocelli to each side on clear fields, but each dark-pigmented in itself. Postantennal organ twice as long as an ocellus, with central boss, four peripheral lobes and one elevated lobe Two long curved dorsal anal spines, each on a basal papilla about as long as itself. Below these there is a single smaller, slightly curved terminal spine mounted on a broad papilla. The terminal spine and papilla equal to half the anal spine and papilla in length. Cuticle coarsely granulate. Rami of tenaculum each with three teeth.

Legs: Claw with two inner teeth, one at about one-third and the other at a half down; and two outer lateral teeth, one to each side, at about halfway down from base. Empodial appendage rudimentary, but more developed than in *T. rubra* A single faintly clavate tenent hair to each foot. This hair appears to be rather hooked than clavate. It is shorter than the claw.

Furcula: Manubrium short and stout, shorter than mucrodens. Mucro with blunt, curved apical tooth and sharper, taller pre-apical tooth connected to base by a broad lamella. Dens without apical scale-like lobe.

Localities: Titahi Bay, under driftwood and debris on the coast; Makara, under stones along the coast; Island Bay, Wellington, amongst rocks; (Author's Coll.); Red Rocks, Cook Strait, beaten from foliage (coll. by R. Forster).

Type: Slide 3/1188. Dominion Museum Collection.

Remarks: This species when found occurs in "nests" or clumps of individuals all tangled together. It is readily recognised in life by its distinctive dark colour.

Triacanthella terrasilvatica sp. nov.* Plate 40, figs. 6-11.

Colour: In life pale-reddish-violet or pale-bluish-violet, fading to pale-pink or very pale-bluish-white in spirit.

Clothing: Numerous short and many relatively long serrated setae; those of Abds. V and VI may be as long as the depth of the segment. The degree of serration of the setae varies from slight on some individuals to very strong on others.

Body: Length up to 1.5 mm. Antennae slightly shorter than the head, the four segments related as 4:4:4:7. Ant. IV with two exsertile knobs at apex; Ant. III with sensory organ as in *purpurea*. Eight ocelli to each side, of which six are large and equal, and the remaining two, the posterior inner two, very slightly reduced in size. Postantennal organ with central boss and four peripheral lobes, the whole slightly larger than anterior ocellus. Rami of tenaculum each with three teeth. Cuticle coarsely granulate. A pair of large curved dorsal anal spines, equal to the hind claw in length, and a single shorter terminal anal spine below these. All mounted on papillae, the dorsal papillae four-fifths the length of their respective spines, the papilla of the terminal spine equalling the spine in length. All these anal spines are curved and relatively longer than the spines of *T. rubra.*

Legs: Claw with two inner teeth, one at one-quarter and the other halfway down from base. Two strong outer teeth, one to each side, at about one-fifth back from apex of claw. No tenent hairs.

Furcula: Mucrodens only slightly longer than manubrium. Dens with one exceptionally long basal seta and several smaller ones. Mucro as in the preceding species, but with apical tooth not quite so strongly curved and pre-apical tooth broader.

Locality: Johnson's Hill, Karori, in damp bush soil just below the layer of leaf mould in the bush. Occurs as single individuals and not very easy to detect. (Author's Coll.) Masterton, on surface of puddles in concrete path, in vast numbers. (Coll. by Miss I. Tankersley.)

Type: Slide 3/1239, Dominion Museum Collection.

Genus ACHORUTES Templeton.

Achorutes armatus Nicolet, 1841.

This species may now be considered as generally distributed throughout the country and very common. An interesting locality was on the surface of a swimming pool in Auckland, collected by W. Cottier.

Achorutes longispinus Tullberg, 1876.

This species was collected recently from foliage at Red Rocks, Cook Strait, by R. Forster.

Achorutes pseudopurpurascens Womersley, 1928.

Like *armatus,* this species can now be regarded as common and generally distributed throughout the country.

Achorutes morbillatus Salmon, 1941.

Now reported from the North Island being taken under the bark of beech trees at Akatarawa by R. Forster.

Achorutes rossi Salmon, 1941.

Recently this species was brought to me as doing damage in a garden at Karori, Wellington, where it appeared in such enormous numbers that it could be swept up by the bucketful from the concrete paths, around and under which it apparently was breeding. It was controlled by application of nicotine sulphate.

Achorutes viaticus Tullberg, 1872.

Bagnall in 1941 studied the *viaticus* group of *Achorutes* in England, and set up two new species, separating the true *viaticus* of Tullberg from the others as being the only one of the group with the rami of the tenaculum bearing four teeth. Recently my attention was focussed on this by the discovery of a species of the *viaticus* group forming a black scum over brackish pools among the rocks at Rocky Bay, Titahi-Bay, Wellington. This proved to be a new species, with the rami of the tenaculum bearing only three teeth. Re-examination of the other New Zealand material previously reported by me as being *Achorutes viaticus* Tullb., reveals that this is not the true *viaticus* as shown by Bagnall, but belongs also to the new species, which I am calling *A. titahiensis.* In 1909 Carpenter

reported *A. viaticus* from Macquarie Island, but whether this was the true *viaticus* or not cannot be fixed from his published statement, and the specimens upon which he based his identification are not available.

Achorutes titahiensis sp. nov. Plate 40, figs 12-21.

[*Achorutes viaticus* Tullb. (in part), Salmon 1937, 1941, not of Tullb.]

Colour: Black all over.

Clothing: Evenly clothed with short setae, which are bent over at one-third along their length and sometimes apically serrated. These are interspersed with longer, straight, stout setae, which are finely serrated on their apical half. The long setae on Abd. IV 0.3 the length of the segment.

Body: Length up to 1.75 mm. Antennae shorter than the head. Ant. IV apically with sensory knob in pit, accessory cone with sense rod and three slightly curved sensory setae. Ant. III with sensory organ situated near joint with fourth segment, and consisting of two sense clubs, each arising from a small pit and separated from each other by a low cuticular fold; the whole flanked on either side by a longer, straighter sense rod. The sense rod on one side is very much more removed from the sense clubs than is the other. Ocelli eight to each side, all equal. Postantennal organ larger than an ocellus, with central boss and 4-5 peripheral lobes. Abd. VI with a pair of small, slightly curved anal spines, each on a basal papilla about one-third to one-half the length of the spine; the spines without the papillae one-fourth to one-fifth the length of the hind claw. Papillae of anal spines may be touching basally or separated up to one and a-half times the width of their bases. Rami of tenaculum each with three teeth.

Legs: Claw with one prominent inner tooth at about half way down, and a pair of small outer teeth, one to each side at about one-quarter back from apex. Empodial appendage needle-like, from half to two-thirds length of claw, with narrow outer lamella and broad inner lamella reaching approximately halfway down. Tenent hairs weakly clavate, in line across the foot, with two to the front feet and three to each of the others, the central one tending to be longer and stouter than the other two.

Furcula: Mucrodens and manubrium of approximately equal length. Dens with one very long basal seta and 5-6 shorter setae. Mucro strongly curved, with apical blunt tooth and broad inner basal lamella, which may be plain but generally carries a sharp and deep incurve at 2/3 from base. Usually there is a smaller, very blunt tooth-like projection in the centre of the apical curve of the lamella. Basal portion of the lamella frequently wavy.

Localities: Titahi Bay, forming a black scum on the surface of brackish pools among the rocks, Rocky Bay; Island Bay, Wellington, amongst the roots of tidal grasses; Silverstream, South Karori, under stones in the stream bed (Author's Coll.); Papanui, Christchurch, on the surface of an unused well (Coll. E. W. Moore).

Type: Slide 3/1216 and Figured Paratypes Slides 3/1205 and 3/1214, Dominion Museum Collection.

Genus PSEUDONTELLA Salmon.

Pseudontella forsteri Salmon, 1942. Recently I have obtained this peculiar species from amongst leaf mould, Johnson's Hill, Karori.

Sub-family NEANURINAE.

Tribe NEANURINI.

Genus NEANURA MacGillivray.

Neanura muscorum Templeton, 1835.

Neanura rosacea (Schott, 1917).

These two species now can be reported as common and generally distributed throughout the country. They may be found in leaf mould, in old logs, and frequently under the bark of trees.

Neanura newmani (Womersley, 1933).

This species must now be recorded from the North Island at Ohakune, where it was found in old logs. (Coll. T. R. Harris.)

Family ONYCHIURIDAE.

Sub-family TULLBERGINAE Bagnall.

Bagnall, in 1935, while studying the British *Tullberginae,* gave one of the characters of this sub-family as "the fact that in no position is there more than 1+1 pseudocelli." If this character is regarded as valid for the sub-family it becomes necessary to separate off *Tullbergia trisetosa* Schaeffer and *Tullbergia australica* Wom., both of which have 2+2 pseudocelli on some segments, together with a new species to be described from New Zealand, into a further new sub-family. As all these species agree in body form, sensory organ of Ant. III and form of postantennal organ with the rest of the species of the *Tullberginae,* I do not think such a separation is desirable. It is necessary, however, to erect a new genus for the reception of the New Zealand species though leaving it in the Sub-family *Tullberginae.*

Genus CLAVAPHORURA nov.

This new genus is separated from the other genera of the *Tullberginae* by the presence on the foot of two groups of clavate tenent hairs, the one group arising from the tibiotarsus on the outer edge near the base of the claw, the other group arising from the tibiotarsus on the inner edge a little further from the base of the claw than the other group. Pseudocelli 2+2 on some segments. Ocelli absent. Antennal base not marked. Pseudocellus of distinctive nine-starred pattern on circular dome. Empodial appendage absent. Genotype the following species.

Clavaphorura septemseta sp. nov. Plate 41, figs. 22-27.

Colour: White all over.

Clothing: Sparsely but evenly clothed with relatively long plain setae.

Body: Length up to 1.16 mm. Antennae about as long as the head. Sensory organ on Ant. III consisting of two bent sense clubs in centre with larger sense club on each side, which is flanked again on each side by a larger. bent sense rod. The whole more or less behind a wavy cuticular fold. Ant. IV apically with exsertile

sensory knob in pit, two large curved sense rods and a short raised finger-like process. Postantennal organ in groove across side of head behind antenna, equal in length to half the width of the basal segment of the antenna, and consisting of 35-36 somewhat rectangular-shaped tubercles arranged in two parallel rows, usually of 16 and 19 or 17 and 19 tubercles respectively. Pseudocelli on raised circular domes with very fine granules, much finer than surrounding body granules, and each with a central nine-pronged star. At base of antennae there are 1 + 1 pseudocelli, back of head 1 + 1, Th. I 1 + 1, Th. II and III 2 + 2, Abd. I–Abd. III each with 1 + 1, Abd. IV 2 + 2, Abd. V 1 + 1. Abd. VI no pseudocelli. Cuticle coarsely granulate. On Abd. VI a pair of anal spines on papillae, each papilla being about three-quarters the length of the spines. The papillae are touching basally.

Legs: Claw without any teeth. Empodial appendage absent. The base of the claw is surrounded by seven long clavate tenent hairs, longer than the claw. These are arranged in two groups, of which the outer group contains three hairs and the inner group four hairs. The inner group is distinctly further from the claw base than the outer group, but the hairs of each group, respectively, are in line across the tibiotarsus. There is a small seta on each side of the claw base.

Locality: Karori Hills, under bark of old logs on exposed hill-sides, altitude 500-800 ft. (Author's Coll.).

Type: Slide 3/1220 and Figured Paratype Slide 3/1221, Dominion Museum Collection.

Family ISOTOMIDAE.

Sub-family Isotominae.

Genus Cryptopygus Willem.

The addition of the following two new species of this primitive genus brings the total number of New Zealand species to eight, which may be conveniently separated by the following key:—

1. Mucro tapering with apical tooth only or with no teeth. ..	..	2
Mucro with apical and pre-apical teeth. ..	..	6
2. Ocelli eight to each side, all large and equal ..	..	3
Ocelli eight to each side, unequal. ..	..	5
3. Claw with inner teeth. ..	..	4
Claw without any teeth, very small blue species. Dens with constriction and with three long ventral setae. ..	*C. granulatus* sp. nov.	
4. Small dark-blue species. Dens with two very long ventral setae almost as long as itself. Postantennal organ not more than twice as long as an ocellus. .	*C. minimus* Salmon.	
Large dark-blue species. Dens with three prominent ventral setae. Postantennal organ three times as long as an ocellus.	*C. terrigenus* sp. nov.	
5. Very dark-blue species. Ocelli seven large and one small to each side. Dens with two long ventral setae and one dorsal apical seta. Postantennal organ twice as long as large ocellus. Mucro with single upturned terminal tooth. ..	*C. okukensis* Salmon.	
Black species, ocelli six large and two small to each side. Mucro tapering without teeth but with narrow inner lamella. ..	*C. niger* Carpenter.	

6. Ocelli eight to each side, all large and equal. 7
Ocelli eight to each side, unequal 8
7. Brilliant-blue species with violet tinge on head. Postantennal organ equal to three ocelli in length. Dens with three prominent ventral setae; mucro without inner lamella. .. .. *C. haweaensis* Salmon.
Entirely blue species. Postantennal organ equal to two ocelli in length. Dens with many long ventral setae; mucro with narrow inner lamella. .. .. *C. loftyensis* Womersley.
8. Jet-black species. Ocelli six large, two small, to each side. Dens with two long ventral setae. Postantennal organ equal in length to two ocelli. .. *C. atratus* Salmon.

Cryptopygus terrigenus sp. nov. Plate 41, figs. 28-29.

Colour: Very dark Prussian blue, generally mottled, and often with narrow, colourless intersegmental bands.

Clothing: Sparsely clothed with very short plain setae.

Body: Length up to 1.5 mm. Antennae a little longer than the head, the four segments related as 20:35:25:48, Ant. IV, with exsertile sensory knob at apex. Ocelli eight to each side all equal. Postantennal organ large elliptical and double outlined, three times as long as an ocellus. Abd. IV, a little longer than Abd. III.

Legs: Claw with a single inner tooth at centre, no outer teeth. Empodial appendage half as long as claw with broad outer lamella, narrow semi-outer lamella and short semicircular inner lamella. Two clavate tenent hairs to each foot. On each of the front feet one tenent hair is very much shorter than the other. Otherwise the tenent hairs are as long as the claw.

Furcula: Manubrium to mucrodens as 16:19. Dens with three long prominent ventral setae and one dorso-lateral apical seta. Mucro long and tapering, with a fine recurved apical tooth, and sometimes a slight pre-apical tooth-like swelling.

Localities: Johnson's Hill, Karori, in leaf mould; Karori Hills in bush-clad gullies amongst leaf mould (Author's Colln).

Type: Slide 3/1228 and Figured Paratype Slide 3/1229 Dominion Museum Collection.

Cryptopygus granulatus sp. nov. Plate 42, figs. 59-61.

Colour: In life pale to medium turquoise blue; mounted ground colour of very pale blue or white overlaid with coarse blotchy aggregates of deep-blue pigment granules more concentrated dorsally and dorso-laterally than ventrally. Legs white with only a few blue granules. Antennae more deeply pigmented, the granules concentrated around the joints. Furcula colourless. Ocelli on ill-defined black pigment patches.

Clothing: Thickly clothed with short plain setae, larger and more numerous around posterior of abdomen.

Body: Length up to .66 mm. Antennae about one-third again as long as head, the four segments related as 12:15:15:25. Ant. IV with apical sensory knob and two long straight apical sensory bristles and several sub-apical ones. Ocelli, eight to each side, all large and equal. Postantennal organ large, oval, double-outlined, almost as broad

as long and 1⅓ times as long as the diameter of an ocellus. Abds. III and IV approximately equal in length. Ventral tube short and dome-like.

Legs: Claw without any teeth. Empodial appendage reaching to about halfway down claw, with the outer lamella narrow reaching to apex, the inner broad reaching two-thirds down from base, and without tooth at angle. Two slender slightly clavate tenent hairs almost as long as claw to each foot, the clavate portion more hook-shaped than clavate.

Furcula: Short. Manubrium to dens to mucro as 11:10:4. Dens with a constriction two-thirds along from base and with three strong ventral setae. Mucro tapering to a fine slightly upturned point.

Locality: D'Urville Island—obtained with a Berlese funnel from leaf mould collected on the Island at an altitude of 1500 ft. in beech forest by Dr. W. R. B. Oliver; Buller's Bush, Levin, in leaf mould. (Author's Coll.).

Type: Slide 3/1300 and Figured Paratype 3/1301. Dominion Museum Collection.

Cryptopygus niger Carpenter, 1925.

Previously known only from Ben More, Canterbury, this species can now be reported from Dean's Bush, Christchurch, under the bark of both rimu and kahikatea trees, where it occurs in large numbers. (Author's Coll.)

Genus Folsomia Willem.

I can now record a native species of this genus from New Zealand. It is distinguished readily from the other three cosmopolitan species of the genus which occur in New Zealand by the absence of ocelli and the presence of a dentate claw.

Folsomia parasitica sp. nov. Plate 41, figs. 30-33.

Colour: White.

Clothing: Evenly clothed with short plain setae and occasional longer ones, the latter more especially around the posterior region.

Body: Length up to 2 mm. Antennae only slightly longer than the head, the four segments related as 5:7:6:11. Ant. IV apically with two short sensory rods. Sensory organ on Ant. III with two completely exposed sense rods. Ocelli absent. Postantennal organ large, elongate, elliptical, constricted at the middle, and about equal in length to half the width of the basal antennal segment. Ventral tube short.

Legs: Claw with single prominent inner tooth at just below centre. No outer teeth. Empodial appendage three-quarters as long as claw, with strong mid-rib, broad inner lamella and narrow outer lamella, both not quite reaching to tip of mid-rib. No tenent hairs.

Furcula: Manubrium to mucrodens as 10:14. Dens annulated and corrugated. Mucro bidentate, the pre-apical tooth about one-third back and much larger than the apical tooth. Dorsally at apex of dens a stout, moderately-long seta.

Locality: Akatarawa, on larvae of the beetle *Chlorochiton suturalis* (Coll. by R. Forster).

Type: Slide 3/1217 and Figured Paratype Slide 3/1222 Dominion Museum Collection.

Genus ACANTHOMURUS Womersley.

Acanthomurus alpinus Salmon, 1941.

This species, previously known only from the South Island mountain regions, can now be recorded from the North Island at Mt. Hector, Tararua Range, under moss and stones and under the bark of old logs 2000-3000 ft. altitude (Coll. R. Forster); Day's Bay, Wellington, amongst leaf mould in bush 500 ft. altitude (Author's Coll.).

Acanthomurus alpinus subspec. **obscuratus** nov. Plate 41, fig. 34.

This subspecies differs from the principal species only in colour. The whole of the ventral surface is coloured a deep-bluish violet, and this colouring extends up the sides to meet broad bands of similar colour which pass around each segment in positions corresponding with the dark markings of the principal form. Antennae and legs deep-violet, darker at the extremities.

Locality: Days Bay, Wellington, amongst leaf mould in bush 500 ft. altitude (Author's Coll.).

Type: Slide 3/1235 Dominion Museum Collection.

Genus ARCHISOTOMA Linnaniemi.

Archisotoma brucei Carpenter, 1906.

I can now record this species from Lyall Bay, Wellington, where I took it from amongst kelp thrown up on the beach.

Genus PROCERURA Salmon.

Procerura montana Salmon, 1941.

The distribution of this species extends to the North Island, as it has now been taken from Mt. Hector, Tararua Range, at 2000 ft. altitude, where it was collected from under the bark of old logs by R. Forster.

Genus PAPILLOMURUS Salmon.

Papillomurus fuscus Salmon, 1941.

Now taken by R. Forster on Mt. Hector, Tararua Ranges, from under the bark of fuchsia trees 1100 ft. altitude, and from under bark of an old log at 3000 ft. altitude.

Genus ISOTOMA Bourlet.

Isotoma maritima Tullberg, 1871.

I have now taken this species at Island Bay, Wellington, where it was beaten from *Salicornia* plants.

Genus PARISOTOMA Bagnall.

Two new species of this genus recently have been found in New Zealand—one a mountain-dwelling form, the other a coastal form. These, with the species previously reported, make five in all known from this country. The following key will assist in their separation:—

1.	Ocelli present.	2
	Ocelli absent.	5
2.	Ocelli six to each side.	3
	Ocelli four to each side, claw without any teeth; mucro tridentate.	*P. notabilis* Schaeffer.

3. Claw without any teeth, Postantennal organ four times as long as ocellus.	*P. sindentata* sp. nov.
Claw with outer teeth but no inner teeth. Postantennal organ smaller.	 4
4. Mucro with three teeth.	*P. pritchardi* Womersley.
Mucro with five teeth.	*P. quinquedentata* sp. nov.
5. Postantennal organ present, large and elliptical, claw without any teeth, mucro tridentate. ..	*P. linnaniemia* Womersley.

Parisotoma sindentata sp. nov. Plate 41, figs. 35-39.

Colour: In life bluish-black with creamy-white intersegmental bands. Mounted the ground colour is creamy-white overlaid with coarse granular pigment, giving the appearance of a bluish-black insect with broad cream intersegmental bands. Ant. I, II and III deep blue-black with the joints marked by narrow bands of cream. Ant. IV pale-blue. Legs and furcula pale-cream with patches of granular pigment.

Clothing: Well clothed with short plain setae and occasional longer stiff setae. No ciliated setae occur.

Body: Length up to 1.5 mm. Antennae about twice as long as the head, the four segments related as 5:8:10:14. Ant. IV apically with small pit containing sense rod and with large exsertile sensory knob; just below the apex a smaller exsertile sensory knob. Ocelli six to each side, the anterior two slightly larger than the remainder. The ocelli are very difficult to determine, as they are set amongst an irregularly defined field of confused, coarse black pigment granules. Postantennal organ very large, oval, double outlined and about four times as long as the anterior ocellus. Ventral tube short and fat. Abd. III almost equal to Abd. IV.

Legs: Claw without any teeth. Empodial appendage about one-half as long as claw, with broad semi-circular inner lamella reaching to two-thirds its length and narrower outer lamella reaching to tip. No tenent hairs.

Furcula: Mucrodens almost three times as long as manubrium. Mucro elongate and tridentate, there being a large apical tooth, a slightly smaller central conical tooth, and a large lateral basal tooth.

Locality: Lyall Bay, Wellington, from kelp lying on beaches among the rocks. Readily obtained by submerging the kelp in rock-pools, when the *Collembola* come out and jump about on the surface of the water.

Type: Slide 3 1127, Dominion Museum Collection.

Parisotoma quinquedendata sp. nov. Plate 41, figs. 40-43.

Colour: In life a pale greyish-blue. Mounted, ochreous ground colour with coarse granular bluish-grey pigment all over. First two antennal segments deep blue, last two pale bluish-grey. Ocellar fields black.

Clothing: Heavily clothed with plain setae and numerous long, strongly ciliated setae, which occur at random anywhere on the body or appendages.

Body: Length up to 1.9 mm., twice as long as the head. The four segments related 6:7:11:11. Ant. IV flattened towards the tip and bearing a sensory pit or groove protected by a fringe of curved sense rods. Apically, Ant. IV is rounded and bears one or

two exsertile sensory knobs. Six equal ocelli to each side. Post-antennal organ pear-shaped, double outlined and equal in size to, or slightly larger than, an ocellus. Abd. III slightly longer than Abd. IV as 16: 14. Ventral tube short and slender.

Legs: Claw with a pair of large outer teeth a little above half-way down outer edge. No inner teeth. Empodial appendage half as long as claw, with broad inner and outer lamellae; the inner lamella truncate on distal half and with a small blunt tooth at the angle. Tenent hairs absent.

Furcula: Mucrodens about two-and-a-quarter times as long as the manubrium. Mucro long with five teeth—an apical and a pre-apical of equal height, a smaller basal tooth at one-third from base, flanked on each side by a strong lateral tooth. One lateral tooth is slightly forward of the other.

Locality: Mount Hector, Tararua Range, 2300 ft. under moss. (Coll. by R. Forster.)

Type: Slide 3/1126, Dominion Museum Collection.

Family TOMOCERIDAE.

Sub-family LEPIDOPHORELLINAE.

Genus LEPIDOPHORELLA Schaeffer.

Lepidophorella australis Carpenter, 1925.

Lepidophorella communis Salmon, 1937.

The distribution of these two species can now be given as common and general throughout the country. They are found particularly in leaf mould, but sometimes under the bark of trees.

Lepidophorella nigra sp. nov. Plate 42, figs. 48-51.

Colour: Greyish-black with narrow white intersegmental bands. The mesotergum intense black. Legs greyish-black. Antennae black with white banded joints. Ant. IV intense black. Furcula black with ochreous streaks on the manubrium. Typically, three inclined ochreous streaks on each side of the mesotergum.

Clothing: Densely clothed with many layers of scales. These scales are of the typical *Lepidophorellan* form and lie over the body in layers set at different angles. When the body surface is closely examined their ribs give a distinct cross-hatched appearance. Setae very much reduced, sometimes entirely absent except for a few on the legs, furcula and antennae.

Body: Length up to 4.5 mm. Ant. I:II:III:IV as 2:5:5:7. Ant. IV with exsertile apical knob and cone bearing sensory hair. Ocelli, eight to each side. Anterior pair the larger; others medium-sized with central outer ocellus usually smaller. Abd. III one and a-half times longer than Abd. IV.

Legs: Claw with two outer lateral teeth as in *L. communis*, but with two large or two large and one very small, or three large, inner teeth. The dentition of the claws may vary over the individual. Tenent hairs absent. Empodial appendage lanceolate, two-thirds length of claw, with two large outer basal teeth, one above the other.

Furcula: Mucro falciform, gently curved with basal scale-like lamella extending from near tip to apex of dens. Corrugated portion of dens passes into finely serrated lamella, which extends over mucro and joins it near point of contact of basal scale-like lamella.

Localities: Turangakuma Range, Hawkes Bay, 3300 ft. in leaf debris; Titahi Bay, in leaf mould (Coll. R. Forster); Karori Hills, in leaf mould, under stones and in old logs (Author's Coll.).

Type: Slide 3 1243, Dominion Museum Collection.

Remarks: I am inclined to the view that this striking species may be a hybrid form produced by the interbreeding of *L. australis* and *L. communis*, as it combines the characters of both of these species.

Genus NOVACERUS Salmon

Novacerus spinosus Salmon, 1941.

Now recorded from the North Island, having been taken on Mount Hector, under moss, 2300 ft. altitude, by R. Forster.

Family ENTOMOBRYIDAE.

Sub-family ENTOMOBRYINAE

Genus SINELLA Brook.

Sinella pulverafusca Salmon, 1941.

This South Island species is now recorded from localities in the North Island as follows:—Mount Hector, Tararua Range, under stones near Field Hut (Coll. R. Forster), and on the Karori Hills, in nests of the ant *Ponera castanea* (Author's Coll.).

Genus DEUTEROSINELLA nov.

Pigmented species of similar facies to *Sinella* but without the ocelli reduced, there being eight to each side. Scales absent. Tibiotarsus on inner surface, with at least one row of stiff, stout, plain setae. Other setae ciliated. Claw with large inner wing-like basal tooth. Tenent hairs present but weak. Genotype the following species.

Deuterosinella fusca sp. nov. Plate 42, figs. 44-47.

Colour: A ground colour of bluish-white overlaid with coarsely-granular bright orange-brown pigment. There are occasional depigmented spots and streaks, especially on Abd. IV. Abd. VI free of pigment Legs bluish-white with dark brown or dark blue granulate pigment bands. Antennae dark blue, granular, but lighter towards the apex. Manubrium dark brown; dens without pigment. Ocelli on irregular black fields.

Clothing: Heavily clothed with short ciliated setae and numerous longer flexed setae, the latter especially along the dorsal surface and at apex of mesotergum. Setae of legs and furcula ciliated except for a double row of longer, stout, plain setae on inner margin of tibiotarsus.

Body: Length up to 2 mm. Antennae twice as long as head, the four segments related as 5:7:6:10. Ant. IV with apical sensory bristle. Ocelli eight to each side; the anterior outer ocellus very large, the sub-posterior inner and sub-posterior outer ocelli each smaller than the remaining four, which are medium-sized and equal. Mesotergum completely overlies prothorax. Abd. IV five times as long as Abd. III.

Legs: Claw with large inner, pointed, basal, wing-like tooth at one-third down with a smaller sharply-pointed normal tooth alongside it. A further prominent inner tooth at two-thirds. A pair of outer

lateral teeth, one to each side, at one-quarter down, and between them a single sharp-pointed central tooth. Empodial appendage lanceolate, two-thirds as long as the claw, with outer basal tooth. A single weak clavate tenent hair, about half as long as the claw, to each foot.

Furcula: Reaching forward to the ventral tube. Manubrium to mucrodens as 15:22. Mucro bidentate with basal spine, the two teeth equal. Uncorrugated portion of dens three times as long as mucro. Mucro surrounded but not over-reached by ciliated setae.

Locality: Taken from wood samples in the timber bin, Forestry Department, Wellington, the samples having come from Days Bay (Coll. D. Hunt).

Type: Slide 3 1200 and Figured Paratype Slide 3 1201, Dominion Museum Collection.

Genus ENTOMOBRYA Rondani.

Entomobrya totapunctata Salmon, 1941.

Now reported from Titahi Bay, beaten from tauhinu scrub on the coast. (Coll. by R. Forster.). Karori, under bark of fuchsia trees. Dean's Bush, Christchurch, under bark of Kahikatea trees. (Author's Coll.).

Entomobrya lamingtonensis Schott, 1917.

A further locality, Karori, under the bark of fuchsia trees. (Author's Coll.)

Entomobrya egmontia Salmon, 1941.

An extraordinary locality for this species was amongst coal in a coal box of a Wellington residence. (Coll. D. K. Ross.)

Entomobrya multifasciata Tullberg, 1871.

Entomobrya nivalis Linne, 1758. *Sensu stricto*, and sub-spec. **immaculata** Schaeffer 1896.

These species can now be recorded as common and generally distributed throughout the country. Usually found in leaf mould, but also occurring under the bark of trees.

Entomobrya exfoliata sp. nov. Plate 42, figs. 52-55.

Colour: In life black with white bands on the legs and sometimes with irregular spots on the body. Mounted: variable, with ground colour of yellowish ochreous overlaid by intense deep violet-black pigment. Typically the whole trunk is deep violet-black, with depigmented spots and streaks of ochreous showing through irregularly, but always with three or four diagonally sloping streaks on the sides of Th. I and Th. II and four or five similar streaks on the sides of Th. III. Depigmented patches occur around the anterior margin of Abd. IV; otherwise the whole of the trunk may be dark pigmented or the pigment may be broken up by small depigmented spots and streaks. The head laterally with deep violet pigment, dorsally ochreous, but between the ocellar fields a large hexagonal area of brownish violet pigment pointed anteriorly and posteriorly. Ant. I deep violet-black; II, III and IV dark ochreous with generally deep violet bands at the joints. Legs ochreous yellow with deep violet bands around all segments. Furcula with the manubrium and base of dens deep violet-black, or ochreous with deep violet pigment along

the dorsal and ventral surfaces. Remainder of mucrodens yellow. Ocellar fields black. The limit of the reduction of the dark pigment on the trunk is reached when it is reduced to a few scattered spots and a narrow but very definite mid-dorsal line along the thorax and first three abdominal segments. This form, however, is very rare.

Clothing: Head, thorax and Abds. I-III dorsally, and Th. I and II laterally, with many long, flexed setae. The body heavily clothed with short, ciliated setae and posteriorly numerous long, ciliated setae. Antennae, legs and furcula heavily clothed with ciliated setae, some of which are very long.

Body: Length up to 2.4 mm. Antennae two and a-half times as long as the head, the four segments related as 10:21:15:19. Eight ocelli to each side, with the anterior pair very large, four medium and two very small. The posterior smaller ocellus almost touching the posterior larger ocellus. Abd. IV seven to eight times as long as Abd. III.

Legs: Claw with outer tooth about one-quarter down, a pair of outer lateral basal teeth reaching about one-third down outer edge, and five inner teeth. A large pair at just before centre, a long, closely-adpressed pair at three-quarters, and a smaller single tooth at seven-eighths. Empodial appendage lanceolate, and reaching to second pair of teeth. A single tenent hair, strongly clavate and as long as the claw, to each foot.

Furcula: Manubrium and mucrodens of equal length. Dens corrugated and annulated, the uncorrugated portion twice the length of the mucro. Mucro elongate, narrow, bidentate, with basal spine, the apical tooth slightly smaller than the pre-apical. Ciliated setae, when present, barely over-reaching the mucro. A double membrane reaches from the apex of the dens to the base of the basal spine on the mucro.

Locality: Titahi Bay, beaten from tauhinu scrub (Coll. R. Forster and Author). Red Rocks, Cook Strait, beaten from coastal scrub (Coll. R. Forster). Karori Hills, beaten from tauhinu scrub (Author's Coll.).

Type: Slide 3/1095 and Figured Paratype Slide 3/1094, Dominion Museum Collection.

Remarks: This species is readily recognised by its jet-black colouring. It is the only black New Zealand Entomobryid. The key given on P. 350 of my paper on the Collembolan Fauna of New Zealand should be amended under 2 by the insertion of the words given below in black print, the remainder of the key remaining exactly as it is at present:—

2.	Colour entirely blue, violet or **black.**	3
	Colour otherwise.	4
3.	**Jet-black with 3–4 diagonally-sloping streaks of yellow on the sides of each of the thoracic segments.**	*E. exfoliata* sp. nov.

Genus Pseudentomobrya Salmon, 1941.

Pseudentomobrya intercolorata sp. nov. Plate 42, figs. 56-58.

Colour: In life grey; mounted, variable from light yellow or greenish yellow to dark brown or almost black, with patches and streaks of yellow showing through irregularly. Head always yellow

with black ocellar fields joined by a black line across the front of the head and between the antennal bases. Legs and furcula always light yellow, the former sometimes tinged with brown. Ant. I yellowish or pale violet, II violet, III and IV very dark violet. Sometimes with a narrow line of dark violet along ventral edges of thoracic pleura Abds. I-III and on the sides of the head.

Clothing: Heavily clothed with ciliated setae and with many long, flexed setae dorsally on head and body. Setae of legs, furcula and antennae all ciliated, but those of Ant. IV shorter than the others.

Body: Length up to 1.3 mm. Antennae twice as long as the head, the four segments related as 4:10:9:14. Ocelli eight to each side; the anterior pair very large, posterior inner pair small, remainder medium. Abd. IV three to three-and-a-half times as long as Abd. III.

Legs: Claw with four inner teeth, being a large pair just beyond centre, a large single tooth at three-quarters, and a very small tooth near apex. A single outer tooth at one-third down outer edge from base. A single strongly clavate tenent hair as long as the claw to each foot. Empodial appendage narrow and from one-third to one-half as long as claw, truncate on inner margin.

Furcula: Reaching forward to ventral tube. Manubrium to mucrodens as 15:20. Dens annulated and corrugated, the unannulated portion three times as long as mucro. Mucro relatively very small, bidentate, the teeth equal, and with a basal spine. The uncorrugated portion of dens strongly but very finely serrated and annulated.

Localities: Hastings, in lawn and under the floor of old shed (Coll. R. Forster). The species was present in large numbers. Makara Coast, under stones on beach; very common (Author's Coll.).

Type: Slide 3/1108 and Figured Paratype Slide 3/1041, Dominion Museum Collection.

Remarks: This species is closest related to *P. interfilixa*. The key for the separation of the species of *Pseudentomobrya* on p. 366 of the Collembolan Fauna of New Zealand can be amended to include this species by adding the words in black print as follows at 4:—

4. **Claw with four inner teeth and one outer tooth. Abd. IV 3–3½ times as long as Abd. III.** .. .. *P. intercolorata* sp. nov.

Claw with two small outer lateral teeth one-fifth down, no inner teeth. Abd. IV 6–8 times longer than Abd. III. .. .. *P. interfilixa.* Salmon.

Genus UREWERA Salmon.

Urewera magna (Salmon, 1937).

This species can now be regarded as common and generally distributed throughout the country. Usually it is found under the bark of trees, old logs, and amongst fallen forest debris.

Urewera magna subspecies **violacea** Salmon, 1938.

This subspecies can now be reported from leaf mould, Burrows Avenue Reserve, Karori, where it is quite common (Author's Coll.).

Urewera flava Salmon, 1938.

Further localities are Johnson's Hill, Karori, from bush debris (Author's Coll.) and Waitakere Ranges, Auckland, from whence it has been reported by Womersley. (*Trans. Roy. Soc. Sth. Aust.* 66 (1) p. 29.)

Urewera quadradentata Salmon, 1941.

Collected on Mount Hector, Tararua Ranges, by R. Forster, under bark of fuchsia trees 1100 ft. altitude, and under moss 2000 ft. altitude.

Genus LEPIDOSIRA Schott, 1925.

Lepidosira indistincta Salmon, 1938.

A further locality is Titahi Bay, where it was beaten from tauhinu scrub by R. Forster.

Sub-family PARONELLINAE.

Genus PARONANA Womersley.

Paronana pigmenta Salmon, 1941.

This South Island species has now been obtained from the North Island, on the Karori Hills, where it was beaten out of dead scrub by R. Forster, and also found under stones (Author's Coll.).

Paronana maculosa Salmon, 1937.

A further locality, Te Mata Park, Havelock Hills, amongst leaf mould (Coll. by R. Forster).

Genus PARACHAETOCERAS Salmon.

Parachaetoceras pritchardi (Womersley, 1936).

Recently collected at Otaki Forks by R. Forster from low shrubs by beating.

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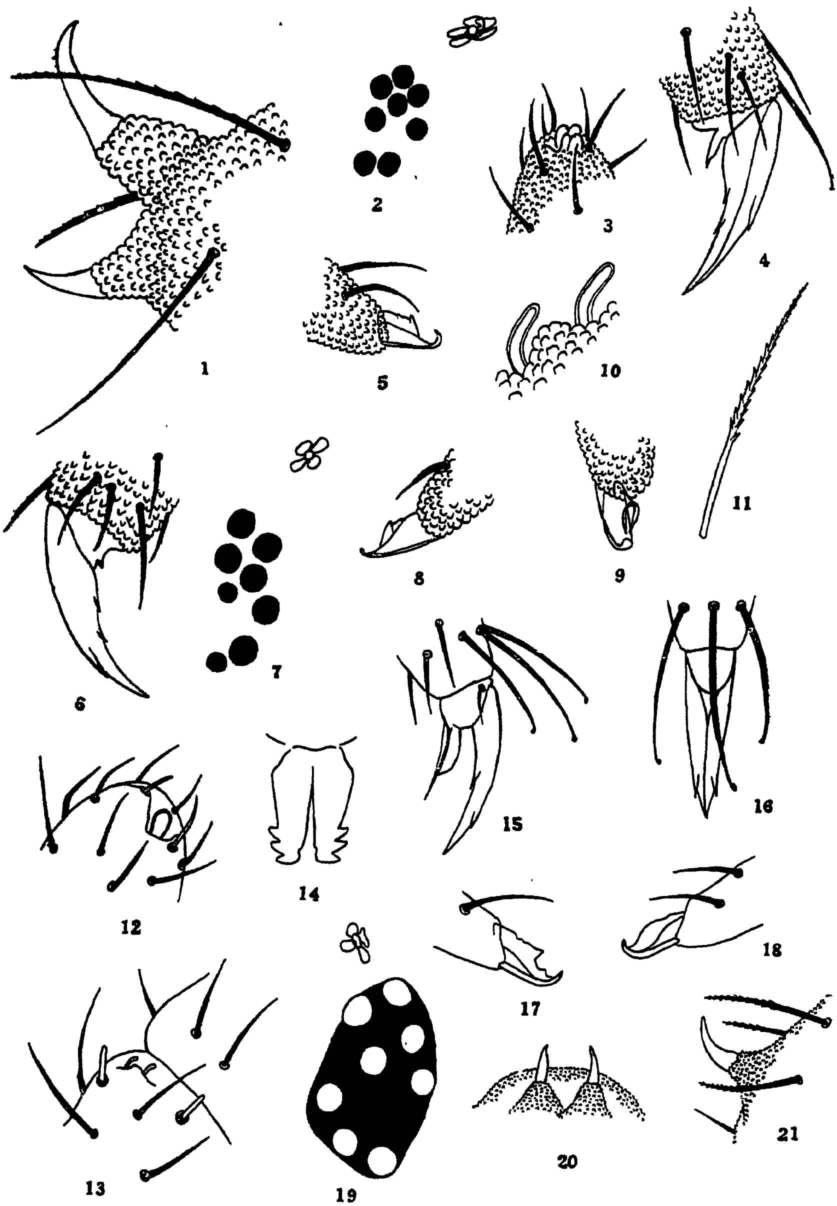
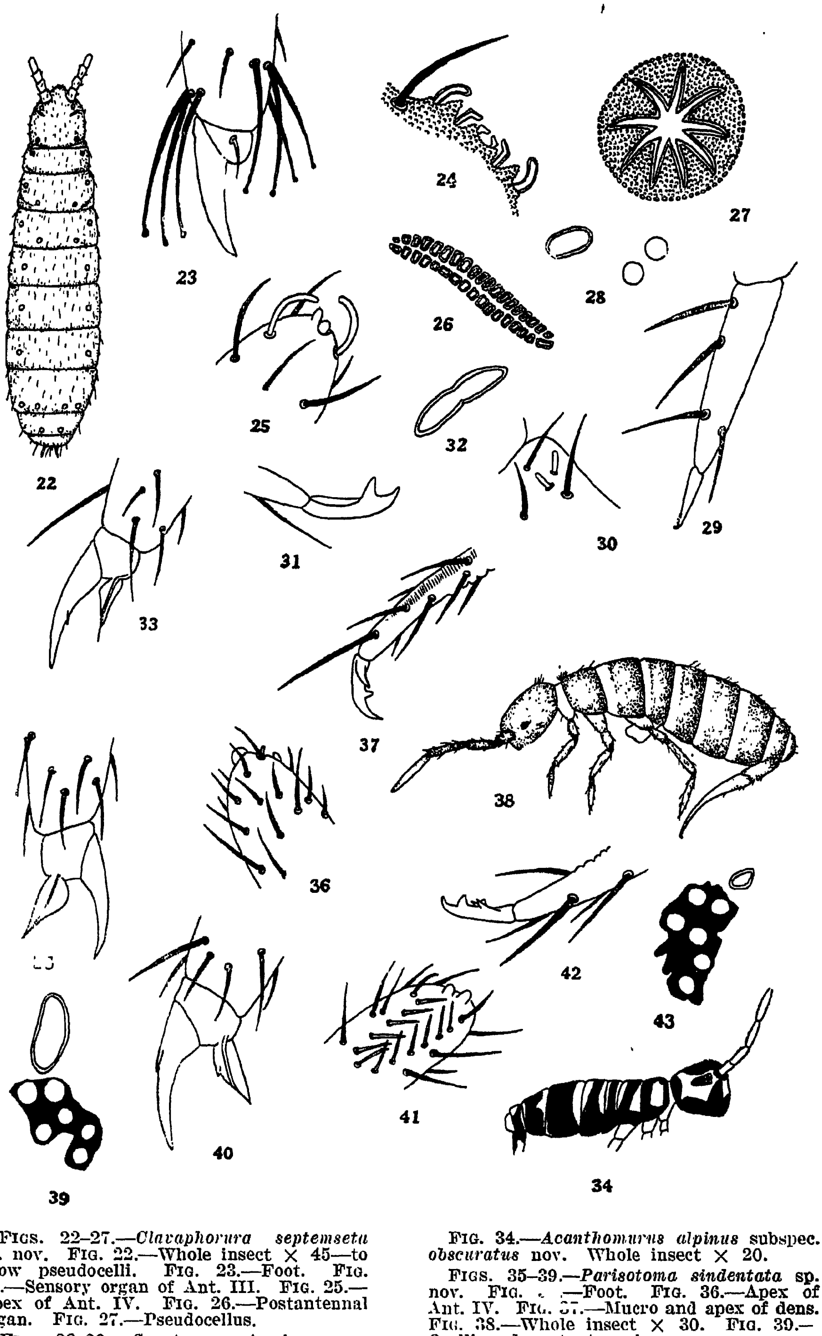


FIGS. 1–5.—*Triacanthella purpurea* sp. nov. FIG. 1.—Anal spines. FIG. 2.—Ocelli and postantennal organ. FIG. 3.—Apex of Ant. IV. FIG. 4.—Foot. FIG. 5.—Mucro and apex of dens.

FIGS. 6–11.—*Triacanthella terrasilvatica* sp. nov. FIG. 6.—Foot. FIG. 7.—Ocelli and postantennal organ. FIG. 8.—Mucro and apex of dens (side view). FIG. 9.—Mucro and apex of dens (ventral view). FIG. 10.—Sensory organ Ant. III. FIG. 11.—Serrated seta from body.

FIGS. 12–21.—*Achorutes titahiensis* sp. nov. FIG. 12.—Apex of Ant. IV. FIG. 13.—Sensory organ on Ant. III. FIG. 14.—Tenaculum. FIG. 15.—Foot (side view). FIG. 16.—Foot (back view). FIG. 17.—Normal mucro. FIG. 18.—Mucro—variation. FIG. 19.—Ocelli and postantennal organ. FIG. 20.—Anal spines from above. FIG. 21.—Anal spines from side.

J. T. S. del.



FIGS. 22–27.—*Clavaphorura septemseta* sp. nov. FIG. 22.—Whole insect × 45—to show pseudocelli. FIG. 23.—Foot. FIG. 24.—Sensory organ of Ant. III. FIG. 25.—Apex of Ant. IV. FIG. 26.—Postantennal organ. FIG. 27.—Pseudocellus.

FIGS. 28–29.—*Cryptopygus terrigenus* sp. nov. FIG. 28.—Anterior ocelli and postantennal organ. FIG. 29.—Dens and mucro.

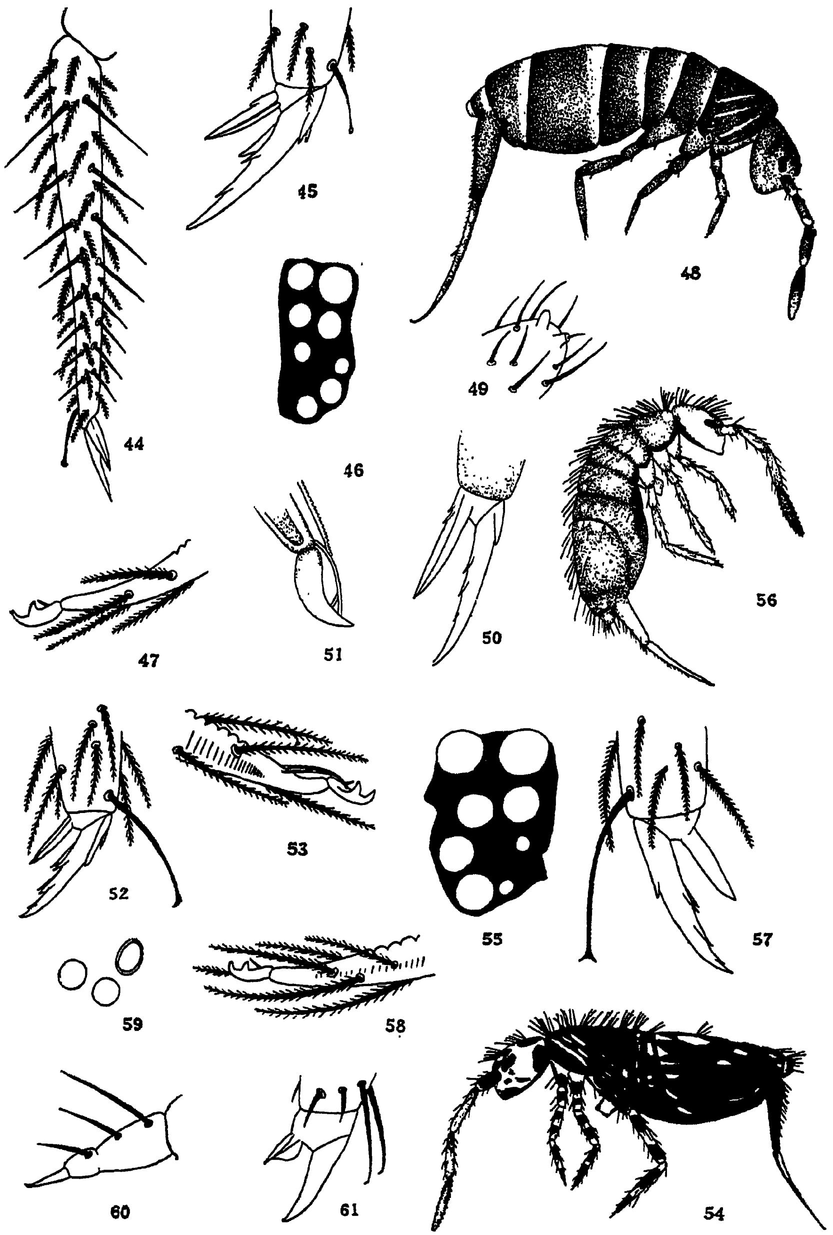
FIGS. 30–33.—*Folsomia parasitica* sp. nov. FIG. 30.—Sensory organ of Ant. III. FIG. 31.—Mucro. FIG. 32.—Postantennal organ. FIG. 33.—Foot.

FIG. 34.—*Acanthomurus alpinus* subspec. *obscuratus* nov. Whole insect × 20.

FIGS. 35–39.—*Parisotoma sindentata* sp. nov. FIG. 35.—Foot. FIG. 36.—Apex of Ant. IV. FIG. 37.—Mucro and apex of dens. FIG. 38.—Whole insect × 30. FIG. 39.—Ocelli and postantennal organ.

FIGS. 40–43.—*Parisotoma quinquedentata* sp. nov. FIG. 40.—Foot. FIG. 41.—Apex of Ant. IV. FIG. 42.—Mucro and apex of dens. FIG. 43.—Ocelli and postantennal organ.

T. T. S. del.



FIGS. 44–47.—*Deuterosinella fusca* sp. nov. FIG. 44.—Tibiotarsus to show simple setae. FIG. 45.—Foot. FIG. 46.—Ocelli. FIG. 47.—Mucro and apex of dens.

FIGS. 48–51.—*Lepidophorella nigra* sp. nov. FIG. 48.—Whole insect × 16. FIG. 49.—Apex of Ant. IV. FIG. 50.—Foot. FIG.. 51.—Mucro and apex of dens.

FIGS. 52–55.—*Entomobrya exfoliata* sp. nov. FIG. 52.—Foot. FIG. 53.—Mucro and apex of dens. FIG. 54.—Whole insect × 20. FIG. 55.—Ocelli.

FIGS. 56–58.—*Pseudentomobrya intercolorata* sp. nov. FIG. 56.—Whole insect × 36. FIG. 57.—Foot. FIG. 58.—Mucro and apex of dens.

FIGS. 59–61.—*Cryptopygus granulatus* sp. nov. FIG. 59.—Anterior ocelli and postantennal organ. FIG. 60.—Dens and mucro. FIG. 61.—Foot.

J. T. S. del.

APPENDIX.

LIST OF AWARDS.

Award of the Hector Memorial Medal and Prize.

1912. L. Cockayne, C.M.G., Ph.D., F.R.S., F.L.S., F.R.S.N.Z.—For researches in New Zealand botany.

1913. T. H. Easterfield, K.B.E., M.A., Ph.D., F.R.S.N.Z.—For researches in chemistry.

1914. E. Best, F.R.S.N.Z.—For researches in New Zealand ethnology.

1915. P. Marshall, M.A., D.Sc., F.G.S., F.R.S.N.Z.—For researches in New Zealand geology.

1916. Lord Rutherford of Nelson, O.M., D.Sc., F.R.S., F.R.S.N.Z.—For researches in physics.

1917. C. Chilton, M.A., D.Sc., M.B., C.M., F.L.S., F.R.S.N.Z.—For researches in zoology.

1918. T. F. Cheeseman, F.L.S., F.Z.S., F.R.S.N.Z.—For researches in New Zealand systematic botany.

1919. P. W. Robertson, M.A., M.Sc., Ph.D.—For researches in chemistry.

1920. S. Percy Smith, F.R.G.S., F.R.S.N.Z.—For researches in New Zealand ethnology.

1921. R. Speight, M.A., M.Sc., F.G.S., F.R.S.N.Z.—For work in New Zealand geology.

1922. C. Coleridge Farr, D.Sc., F.R.S., F.R.S.N.Z.—For research in physical science and more particularly work in connection with the magnetic survey of New Zealand.

1923. G. V. Hudson, F.E.S., F.R.S.N.Z.—For researches in New Zealand entomology.

1924. D. Petrie, M.A., F.R.S.N.Z.—For researches in New Zealand botany.

1925. B. C. Aston, F.I.C., F.R.S.N.Z.—For the investigation of New Zealand chemical problems.

1926. H. D. Skinner, M.A., D.Sc., F.R.S.N.Z.—For research in ethnology.

1927. C. A. Cotton, D.Sc., F.G.S., F.R.S.N.Z.—For researches in the geomorphology of New Zealand.

1928. D. M. Y. Sommerville, M.A., D.Sc., F.R.S.N.Z.—For his general mathematical work and particularly for his investigations in non-Euclidean geometry.

1929. G. M. Thomson, F.L.S., F.R.S.N.Z.—For researches on the acclimatisation of animals in New Zealand and on the natural history of New Zealand fishes.

1930. J. E. Holloway, L.Th., D.Sc., F.R.S., F.R.S.N.Z.—For researches in the life-histories of New Zealand *Pteridophytes.*

1931. W. P. Evans, M.A., Ph.D., F.R.S.N.Z.—For research in pure and applied chemistry.

1932. Te Rangi Hiroa (P. H. Buck), M.D., Ch.B (N.Z.), F.R.S.N.Z.—For researches in Maori ethnology.

1933. W. N. Benson, B.A., D.Sc., F.G.S., F.R.S.N.Z., and J. Marwick, M.A., D.Sc., F.R.S.N.Z.—For researches in New Zealand geology.

1934. G. E. Weatherburn, M.A., D.Sc.—For outstanding original work in mathematics, especially in the use of vector analysis.

1935. W. B. Benham, K.B.E., M.A., D.Sc., F.R.S., F.R.S.N.Z.—For original researches in New Zealand zoology.

1936. W. R. B. Oliver, D.Sc., F.L.S., F.Z.S., F.R.S.N.Z.—For research in New Zealand botany.

1937. J. R. Hosking, B.Sc., Ph.D.—For research in the chemistry of New Zealand plants.

1938. H. W. Williams, M.A., Litt.D., F.R.S.N.Z.—For researches in ethnology.

1939. J. A. Bartrum, M.Sc., F.R.S.N.Z.—For researches in geology.

1940. D. B. Macleod, M.A., D.Sc., F.R.S.N.Z.—For outstanding work in molecular physics.

1941. H. J. Finlay, D.Sc., F.R.S.N.Z.—For researches on mollusca and foraminifera.

1942. H. H. Allan, M.A., D.Sc., F.L.S.—For researches in New Zealand botany.

Award of the Hutton Memorial Medal.

1911. W. B. Benham, K.B.E., M.A., D.Sc., F.R.S., F.R.S.N.Z.—For researches in New Zealand zoology.

1914. L. Cockayne, C.M.G., Ph.D., F.R.S., F.L.S., F.R.S.N.Z.—For researches in the ecology of New Zealand plants.

1917. P. Marshall, M.A., D.Sc., F.G.S., F.R.S.N.Z.—For researches in New Zealand geology.

1920. J. E. Holloway, L.Th., D.Sc., F.R.S., F.R.S.N.Z.—For researches in New Zealand pteridophytic botany.

1923. J. A. Thomson, M.A., D.Sc., F.G.S., F.R.S.N.Z.—For researches in geology.

1926. C. Chilton, M.A., D.Sc., LL.D., M.B., C.M., F.L.S., F.R.S.N.Z.—For his continuous researches on the amphipodous crustacea of the Southern Hemisphere.

1929. G. V. Hudson, F.E.S., F.R.S.N.Z.—For research in entomology.

1932. J. A. Bartrum, M.Sc., F.R.S.N.Z.—For researches in geology.

1935. G. H. Cunningham, D.Sc., F.R.S.N.Z.—For research in mycological botany.

1938. David Miller, Ph.D., M.Sc., F.R.S.N.Z., F.R.E.S., F.L.S.N.S.W.—For researches in entomology.

1941. H. H. Allan, M.A., D.Sc., F.L.S., F.R.S.N.Z.—For botanical researches.

Grants from the Hutton Memorial Research Fund.

1919. Miss M. K. Mestayer £10, for work on the New Zealand mollusca.

1923. Professor P. Marshall £40, for study of the upper cretaceous ammonites of New Zealand.

1927. Miss M. K. Mestayer £30, for research on brachiopoda and mollusca.

1928. Dr C. Chilton £50, for research on New Zealand and Antarctic crustacea.

1928. Dr H. J. Finlay £10, for research on New Zealand mollusca.

1932. Dr F. J. Turner £30, for geological expedition to south-west portion of Otago.

1932. Mr C. E. Christensen £25, for collecting hybrid plants at Hanmer.

1932. Mr L. C. King £20, for geological study of Tertiary rocks at Awatere Valley, Marlborough.

1932. Dr O. H. Frankel £25, for cytological research.

1932. Waitemata Harbour Survey Committee £25, for ecological survey of Waitemata Harbour.

1933. Mr G. M. Thomson £30, for preparation of illustrated catalogue of New Zealand crustacea.

1933. Mr K. M. Ruddall £5, for zoological research on Little Barrier Island.

1934. Mr L. C. King £25, for geological research in the Marlborough District.

1934. Messrs R. A. Falla and A. W. B. Powell £40, for research on the molluscan and bird fauna of the Sub-Antarctic Islands of New Zealand.

1934. Dr. W. R. B. Oliver £50, for assistance in publishing a monograph on the genus *Coprosma*.

1935. Dr P. Marshall £40, for purchase of microscope goniometer and field work in connection with mineral "tuhualite" of Mayor Island and the occurrence of the spheroidal granite of Karamea.

1935. Mr H. Service £4 10s, for geological research at the Bluff.

1936. Mr C. O. Hutton, £30, for field study of the metamorphic and intrusive rocks of the Lake Wakatipu region.

1938. Dr. F. J. Turner, £15, to defray cost of cutting oriented sections of Otago schists.

1939. Mr L. E. Richdale, £20, for expenses in connection with the ringing of birds.

1941. Dr. F. J. Turner, £25, for research on the structural petrology of metamorphic rocks in Central Otago and Fiordland.

1941. Dr. S. N. Slater, £10, for work on the poisonous constituents of tutu.

1942. Mr L. E. Richdale, £40, for ornithological research at Stewart Island.

1942. Dr. F. J. Turner, £25, for structural petrology of metamorphic rocks.

AWARD OF THE HAMILTON MEMORIAL PRIZE.

1923. J. G. Myers, D.Sc.

1926. H. J. Finlay, D.Sc., F.R.S.N.Z., and J. Marwick, D.Sc., F.R.S.N.Z

1934. L. C. King, M.Sc., Ph.D.

1937. C. O. Hutton, M.Sc., Ph.D., F.G.S.

AWARD OF THE T. K. SIDEY SUMMER-TIME MEDAL AND PRIZE.

1933. Lord Rutherford of Nelson, O.M., D.Sc., F.R.S., F.R.S.N.Z.

Special award to Mr G. V. Hudson, F.E.S., F.R.S.N.Z.

1936. Sir Leonard Hill, Kt., M.B., LL.D.

THE ROYAL SOCIETY OF NEW ZEALAND.

COUNCIL FOR 1942-43.

ESTABLISHED UNDER AN ACT OF THE GENERAL ASSEMBLY OF NEW ZEALAND ENTITULED THE NEW ZEALAND INSTITUTE ACT, 1867; RECONSTITUTED UNDER THE NEW ZEALAND INSTITUTE ACT, 1903 CONTINUED UNDER THE NEW ZEALAND INSTITUTE ACT, 1908, AND RECONSTITUTED UNDER THE ROYAL SOCIETY OF NEW ZEALAND ACT, 1933.

HONORARY PATRON.

His Excellency the Governor-General.

COUNCIL.

EX OFFICIO.

The Hon. the Minister for Scientific and Industrial Research.

PRESIDENT.

Lieut.-Colonel G. Archey, O.B.E., M.A., F.R.S.N.Z., F.Z.S.

VICE-PRESIDENT.

Dr. H. H. Allan, M.A., F.L.S.

GOVERNMENT REPRESENTATIVES.

Professor E. R. Hudson, B.Agr., BSc. (1941).
Lieut.-Col. E. Marsden, O.B.E., F.R.A.S., F.R.S.N.Z. (1941).
Mr. B. C. Aston, F.I.C., F.R.S.N.Z. (1942).
Dr. W. R. B. Oliver, F.L.S., F.R.S.N.Z. (1942).

ELECTED BY MEMBER BODIES.

Auckland Institute ..	Mr. A. T. Pycroft.
	Professor H. W. Segar, M.A., F.R.S.N.Z.
Wellington Branch..	Dr. H. H. Allan, M.A., F.L.S., F.R.S.N.Z.
	Dr. L. I. Grange, A.O.S.M., F.R.S.N.Z.
Canterbury Branch..	Dr. R. A. Falla, M.A., F.R.S.N.Z.
	Dr. F. W. Hilgendorf, M.A., F.R.S.N.Z.
Otago Branch	Dr. C. M. Focken, B.M.E., B.Sc.
	Dr. F. J. Turner, F.R.S.N.Z.
Hawke's Bay Branch	Mr. G. V. Hudson, F.E.S., F.R.S.N.Z.
Nelson Institute ..	Dr. D. Miller, F.R.S.N.Z.
Southland Branch ..	Professor W. P. Evans, M.A., Ph.D., F.R.S.N.Z.
Manawatu Branch ..	Mr. M. A. Eliott.

CO-OPTED MEMBER.

Dr. P. Marshall, M.A., F.G.S., F.R.G.S., F.R.S.N.Z.

OFFICERS FOR THE YEAR 1941-42.

PRESIDENT: Lieut.-Col. G. Archey, O.B.E., M.A., F.Z.S., F.R.S.N.Z.
VICE-PRESIDENT: Dr. H. H. Allan, F.L.S., F.R.S.N.Z.
HON. TREASURER: Mr. M. A. Eliott.
HON. EDITOR: Dr. J. Marwick, F.R.S.N.Z.
HON. LIBRARIAN: Professor W. P. Evans, M.A., Ph.D., F.R.S.N.Z.
HON. RETURNING OFFICER: Professor H. W. Segar, M.A., F.R.S.N.Z.
SECRETARY: Miss M. Wood, Royal Society of New Zealand, Victoria University College, Wellington, New Zealand.

MEMBER BODIES.

Name of Society.	Secretary's Name and Address.	Date of Affiliation.
Auckland Institute	Lt.-Col. G. Archey, Institute and Museum, Auck.	June 10, 1868
Wellington Branch of the Royal Society of N.Z.	Mr J. T. Salmon, Dominion Museum, Wellington.	June 10, 1868
Canterbury Branch of the Royal Society of N.Z. ..	Mr. R. M. Allison, Wheat Research Institute, Christchurch.	October 22, 1868
Otago Branch of the Royal Society of New Zealand	Dr. H. D. Skinner, Otago Museum, Dunedin.	October 18, 1869
Nelson Institute	Mr. W. C. Davies, Cawthron Institute, Nelson.	December 20, 1883
Hawke's Bay Branch of the Royal Society of New Zealand	Mr. C. F. H. Pollock, P.O. Box 305, Napier.	March 31, 1875
Manawatu Branch of the Royal Society of New Zealand	Dr. J. Melville, 83 Marne Street, Palmerston North.	1935
Southland Branch of the Royal Society of New Zealand	Mr. A. D. Nisbet, 264 Dee Street, Invercargill.	October 31, 1939

FORMER MANAGER AND EDITOR
(Under the New Zealand Institute Act, 1867.)

1867-1903.—Sir James Hector, M.D., K.C.M.G., F.R.S.

PAST PRESIDENTS.

1903-04.—Hutton, Captain Frederick Wollaston, F.R.S.
1905-06.—Hector, Sir James, M.D., K.C.M.G., F.R.S.
1907-08.—Thomson, George Malcolm, F.L.S., F.R.S.N.Z.
1909-10.—Hamilton, Augustus.
1911-12.—Cheeseman, Thomas Frederick, F.L.S., F.Z.S., F.R.S.N.Z.
1913-14.—Chilton, Charles, M.A., D.Sc., LL.D., F.L.S., C.M.Z.S., F.R.S.N.Z.
1915. ——Petrie, Donald, M.A., Ph.D., F.R.S.N.Z.
1916-17.—Benham, Sir William Blaxland, M.A., D.Sc., F.R.S., F.Z.S., F.R.S.N.Z.
1918-19.—Cockayne, Leonard, C.M.G., Ph.D., F.R.S., F.L.S., F.R.S.N.Z.
1920-21.—Easterfield, Sir Thomas Hill, M.A., Ph.D., F.I.C., F.C.S., F.R.S.N.Z.
1922-23.—Kirk, Harry Borrer, M.A., F.R.S.N.Z.
1924-25.—Marshall, Patrick, D.Sc., F.G.S., F.R.S.N.Z.
1926-27.—Aston, Bernard Cracroft, F.I.C., F.C.S., F.R.S.N.Z.
1928. ——Thomson, J. Allan, M.A., D.Sc., F.G.S., F.R.S.N.Z. (Mr B. C. Aston reappointed May, 1928, *vice* Dr J. Allan Thomson, deceased).
1929-30.—Farr, Clinton Coleridge, D.Sc., F.R.S., F.P.S.L., F.R.S.N.Z.
1931-32.—Segar, Hugh William, M.A., F.R.S.N.Z.
1933-34.—Speight, Robert, M.A., M.Sc., F.G.S., F.R.S.N.Z.
1935-36.—Williams, Rt. Rev. Bishop, M.A., Litt.D. (Cantab & N.Z.), F.R.S.N.Z.
1937-38.—Evans, Prof. W. P., M.A., Ph.D., F.R.S.N.Z.
1939-40.—Holloway, Rev. J. E., L.Th., D.Sc., F.R.S., F.R.S.N.Z.

HONORARY MEMBERS.

	Elected
Aitken, Alexander Craig, M.A., D.Sc., F.R.S., University of Edinburgh	1940
Andrews, E. C., B.A., F.G.S., 32 Benelong Crescent, Bellevue Hill, Sydney	1934
Buck, P. (Te Rangi Hiroa), M.D., Ch.B. (N.Z.), F.R.S.N.Z., Bishop Museum, Honolulu	1934
Butler, Sir Edwin John, M.D., D.Sc., C.I.E., F.R.S., Secretary Agricultural Research Council, 6a Dean's Yard, Westminster, London, S.W.1	1939
Chapman, F., A.L.S., Hon. F.R.M.S., F.G.S., Honorary Palaeontologist, National Museum, 17 Threadneedle St., Balwyn, Melbourne, Victoria	1932
Compton, Professor A. H., Ph.D., Sc.D., LL.D., University of Chicago, Chicago, U.S.A.	1934
Diels, Professor L., Ph.D., Director Botanic Garden and Museum, Dahlem, Berlin	1907
Einstein, Professor Albert, F.R.S., Princeton University, New Jersey, U.S.A.	1924
Fleming, J. A., D.Sc., Director of Department of Terrestrial Magnetism, 5241 Broad Branch Road, N.W. Washington, D.C., U.S.A.	1939
Gatenby, J. B., M.A., Ph.D., B.Sc., D.Sc., Professor of Zoology and Comparative Anatomy, University, Dublin	1934
Hall, Sir Alfred D., K.C.B., M.A., D.Sc., F.R.S., Ministry of Agriculture, London	1920
Hopkins, Sir Frederick Gowland, O.M., M.A., M.B., D.Sc., F.R.S., University of Cambridge	1937
Jaggar, Dr T. A., Director of Volcanological Observatory, Volcano House, P.O., Hawaii	1927
Jeans, Sir James H., D.Sc., F.R.S., Cleveland Lodge, Dorking, Surrey ..	1929
Jenness, Dr Diamond, M.A., Division of Anthropology, National Museum of Canada, Ottawa	1941
Keith, Sir Arthur, Kt., M.D., F.R.C.S., LL.D., D.Sc., F.R.S., Buckston Browne Farm, Downe, Farnborough, Kent	1939
Malinowski, Bronislaw, Ph.D. (Cracow), D.Sc. (Lond.), Prof. of Social Anthropology, London School of Economics, London	1936
Marshall, Sir Guy A. K., C.M.G., F.R.S., 16 Cranley Place, London, S.W.7	1933
Mawson, Sir Douglas, B.E., D.Sc., F.R.S., The University, Box 498, Adelaide, South Australia	1920
Mortensen, Theodor, Ph.D., Director of the Department of Invertebrates of the Zoological Museum, Copenhagen	1927
Rivett, Sir David, K.C.M.G., M.A., B.Sc. (Oxon), D.Sc. (Melb.) ..	1937
Robinson, Sir Robert, Kt., M.A.. D.Sc., F.R.S., The Dyson Perrins Laboratory, South Park Road, Oxford	1939
Russell, Sir John, D.Sc., F.R.S., Director of Rothamsted Experiment Station, Harpenden	1928
Seward, Professor Sir Albert C., Kt., Sc.D., F.R.S., Botany School, Cambridge	1928
Skottsberg, Professor C., D.Sc., Botaniska Tradgarden, Goteborg, Sweden	1938
Smuts, Rt. Hon. Field Marshal J. C., Pretoria, South Africa	1942
Wilckens, Dr. Otto, Bonn University, Bonn	1936
Woods, Henry, M.A., F.R.S., F.G.S., Sedgwick Museum, Cambridge ..	1920

FORMER HONORARY MEMBERS.

	Elected
Agardh, Dr J. G.	1900
Agassiz, Professor Louis	1870
Arber, Dr E. A. Newell	1914
Armstrong, Prof. H. E., F.R.S.	1927
Avebury, Lord, P.C., F.R.S.	1900
Baird, Professor Spencer F.	1877
Balfour, Prof. I. Bayley, F.R.S.	1914
Bateson, Professor W., F.R.S.	1915
Beddard, Dr F. E., F.R.S.	1906
Beneden, Professor J. P. van	1888
Berggren, Dr S.	1876
Bowen, Sir George Ferguson, G.C.M.G.	1873
Brady, Dr G. S., F.R.S.	1906
Bragg, Professor Sir William, O.M., K.B.E., F.R.S.	1923
Bruce, Dr W. S.	1910
Carpenter, Dr W. B., F.R.S.	1883
Chree, Dr Charles, F.R.S.	1924
Clarke, Rev. W. B., F.R.S.	1876
Codrington, Rev. R. H., D.D.	1894
Curie, Madame Marie	1927
Darwin, Charles, M.A., F.R.S.	1871
Darwin, Sir George, F.R.S.	1909
David, Professor T. Edgeworth, F.R.S.	1904
Davis, J. W.	1891
Davis, Professor W. Morris	1913
Dendy, Dr A., F.R.S.	1907
Drury, Captain Byron	1870
Ellery, R. L. J., F.R.S.	1883
Etheridge, Professor R., F.R.S.	1876
Ettingshausen, Baron von	1888
Eve, H. W., M.A.	1901
Filhol, Dr H.	1875
Finsch, Professor Otto	1870
Flower, Professor W. H., F.R.S.	1870
Fraser, Sir James G., Kt., O.M., D.C.L., F.R.S.	1920
Garrod, Professor A. H., F.R.S.	1878
Goebel, Professor Dr Carl von	1901
Goodale, Prof. G. L., M.D., LL.D.	1891
Gray, Dr J. E., F.R.S.	1871
Gray, Professor Asa	1885
Gregory, Professor J. W., F.R.S.	1920
Grey, Sir George, K.C.B.	1872
Gunther, Dr A., F.R.S.	1873
Haddon, Dr. A. C., F.R.S.	1925
Haldane, J. S., M.A., M.D., LL.D., F.R.S.	1928
Haswell, Prof. W. A., F.R.S.	1914
Hedley, Charles	1924
Hemsley, Dr W. Botting, F.R.S.	1913
Hill, Sir Arthur W., K.C.M.G., Sc.D., D.Sc., F.R.S.	1928
Hochstetter, Dr Ferdinand von	1870
Hooker, Sir J. D., F.R.S.	1870
Howes, G. B., F.R.S.	1901
Huxley, Thomas H., F.R.S.	1872
Klotz, Professor Otto J.	1903
Langley, S. P.	1896
Lindsay, W. L., M.D.	1871
Liversidge, Professor A., F.R.S.	1890
Lotsy, Dr J. P.	1927
Lydekker, Richard, F.R.S.	1896
Lyell, Sir Charles, F.R.S.	1873
Massart, Professor Jean	1916
McCoy, Professor Sir F.	1888
McLauchlan, Robert	1874
Massee, George	1900
Masson, Sir D. Orme, F.R.S.	1928
Mellor, J. W., D.Sc.,	1919
Meyrick, E., F.R.S.	1907
Milne, J., F.R.S.	1906
Mitten, William, F.R.S.	1895
The Most Noble the Marquis of Normanby	1880
Mueller, Dr Ferdinand von, F.R.S.	1870
Muller, Professor Max, F.R.S.	1878
Newton, Alfred, F.R.S.	1874
Nordstedt, Professor Otto	1890
Owen, Professor Richard, F.R.S.	1870
Pickard-Cambridge, Rev. O.	1873
Richards, Rear-Admiral G. H.	1870
Riley, Professor C. V.	1890
Rolleston, Professor G., M.D., F.R.S.	1875
Ross, Sir Ronald	1929
Rutherford, Lord, F.R.S.	1904
Sars, Professor G. O.	1902
Schmidt, Professor J.	1930
Sclater, Dr P. L., F.R.S.	1875
Sharp, Dr D.	1877
Sharp, R. B., F.R.S.	1885
Stebbing, Rev. T. R. R., F.R.S.	1907
Stokes, Vice-Admiral J. L.	1872
Tenison-Woods, Rev. J. E.	1878
Thiselton-Dyer, Sir W. T., F.R.S.	1894
Thomson, Prof. Wyville, F.R.S.	1874
Thomson, Sir Arthur	1928
Thomson, Sir William, F.R.S.	1883
Tillyard, R. J., F.R.S.	1935
Wallace, Sir A. R., F.R.S.	1885
Weld, Frederick A.	1877

FELLOWS OF THE ROYAL SOCIETY OF NEW ZEALAND.

ORIGINAL FELLOWS.

(See *New Zealand Gazette*, 20th November, 1919.)

‡*Aston, Bernard Cracroft, F.I.C., F.C.S.
*†‡Benham, Sir William Blaxland, K.B.E., M.A., D.Sc., F.R.S., F.Z.S.
§*Best, Elsdon.
§‡*Cheeseman, Thomas Frederick, F.L.S., F.Z.S.
§‡†*Chilton, Charles, M.A., D.Sc., LL.D., M.B., C.M., F.L.S., C.M.Z.S.
§‡†*Cockayne, Leonard, C.M.G., Ph.D., F.R.S., F.L.S.
*Easterfield, Sir Thomas Hill, K.B.E., M.A., Ph.D., F.I.C., F.C.S.
§‡*Farr, Clinton Coleridge, D.Sc., F.P.S.L., F.R.S.
§Hogben, George, C.M.G., M.A., F.G.S.
†*Hudson, George Vernon, F.E.S.
‡Kirk, Harry Borrer, M.A.
‡†*Marshall, Patrick, M.A., D.Sc., F.G.S., F.R.G.S., F.E.S.
§‡*Petrie, Donald, M.A., Ph.D.
§*Rutherford of Nelson, Lord, O.M., D.Sc., Ph.D., LL.D., F.R.S.
‡Segar, Hugh William, M.A.
§*Smith, Stephenson, Percy, F.R.G.S.
‡*Speight, Robert, M.A., M.Sc., F.G.S.
§Thomas, Sir Algernon Phillips Withiel, K.C.M.G., M.A., F.L.S.
§‡*Thomson, Hon. George Malcolm, F.L.S., M.L.C.
§‡†Thomson, James Allan, M.A., D.Sc., A.O.S.M., F.G.S.

FELLOWS ELECTED.

	Date
*†Allan, Harry Howard, M.A., D.Sc., F.L.S.	1928
Allan, Robin Sutcliffe, M.Sc. (N.Z.), Ph.D.	1940
Andersen, Johannes Carl, M.B.E.	1923
Archey, Gilbert, O.B.E., M.A., F.Z.S.	1932
Askew, Henry Oscar, M.A., Ph.D., D.I.C., F.I.C., F.N.Z.I.C., F.C.S.	1939
*†Bartrum, John Arthur, M.Sc.	1928
*Benson, William Noel, B.A., D.Sc., F.G.S., F.R.G.S.	1926
Briggs, Lindsay Heathcote, D.Sc. (N.Z.), D.Phil. (Oxon.), F.N.Z.I.C., F.C.S.	1942
§Brown, J. Macmillan, M.A., LL.D.	1925
*Buck, Peter H. (Te Rangi Hiroa), M.D., Ch.B. (N.Z.)	1925
*Cotton, Charles Andrew, D.Sc., A.O.S.M., F.G.S.	1921
†Cunningham, Gordon Herriot, M.Sc., Ph.D., D.Sc.	1929
Curtis, Kathleen M., M.A., D.I.C., D.Sc., F.L.S.	1936
§Denham, Henry George, M.A., D.Sc., Ph.D	1933
Donovan, William, M.Sc., F.I.C.	1938
‡*Evans, William Percival, M.A., Ph.D.	1930
Falla, Robert Alexander, M.A., D.Sc.	1941
*Finlay, Harold John, D.Sc.	1939
Grange, Leslie Iscott, D.Sc., A.O.S.M.	1942
Henderson, John, M.A., D.Sc., B.Sc. (in Engineering)	1929
§Hilgendorf, Frederick William, M.A., D.Sc.	1921
‡†*Holloway, John Ernest, L.Th., D.Sc., F.R.S.	1921
§Kidson, Edward, O.B.E., M.A., D.Sc.	1931
§Laing, Robert Malcolm, M.A., B.Sc.	1922
§Maclaurin, James Scott, D.Sc., F.C.S.	1926
*Macleod, Donald Bannerman, M.A., D.Sc.	1935
Marsden, Ernest, C.B.E., D.Sc., F.R.A.S.	1922
*Marwick, John, M.A., D.Sc.	1935
†Miller, David, M.Sc., Ph.D.	1931
§Morgan, Percy Gates, M.A., F.G.S., A.O.S.M.	1922
*Oliver, Walter Reginald Brook, D.Sc., F.L.S., F.Z.S.	1927
Park, James, Hon.M.Inst.M.M.Lond., F.G.S.	1921
§Philpott, Alfred, F.E.S.	1930
Powell, Arthur William Baden	1940
Rigg, Sir Theodore, M.A., M.Sc., F.I.C.	1932
*Skinner, Henry Devenish, M.A., D.Sc.	1927
§Smith, William Herbert Guthrie	1924
§*Sommerville, Duncan McLaren Young, M.A., D.Sc., F.R.S.E., F.R.A.S.	1922
§Tillyard, Robin John, M.A., D.Sc., F.R.S., F.L.S., F.E.S.	1924
§Turner, E. Phillips, F.R.G.S.	1936
Turner, Francis John, D.Sc., F.G.S.	1938
*‡§Williams, Herbert William, Rt. Rev. Bishop, M.A., Litt.D.	1923

* Hector Medallist; † Hutton Medallist; ‡ Past President; § Deceased.

GENERAL INDEX

NOTE.—New genera, species, etc., are printed in ***black type.***